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APPRAISAL OF THE GROUND-WATER RESERVOIR AREAS IN RHODE ISLAND

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RHODE ISLAND
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GEOLOGICAL BULLETIN NO. 11

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State of Rhode Island and Providence Plantations

Appraisal of the Ground-Water Reservoir Areas in Rhode Island

By

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RHODE ISLAND
GEOLOGICAL BULLETIN NO. 11

Prepared by the
UNITED STATES GEOLOGICAL SURVEY
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APPRAISAL OF THE GROUND-WATER RESERVOIR AREAS IN RHODE ISLAND

By S. M. LANG

ABSTRACT

The geologic formations in Rhode Island may be divided into two major groups according to their water-bearing characteristics: (1) till—including mixed deposits—and bedrock, and (2) outwash. The till and bedrock formations in the State do not yield large quantities of water to individual wells; large ground-water supplies can be obtained only from permeable sand and gravel in the outwash deposits.

The State was divided into 17 ground-water study areas (including Block Island) according to the occurrence, extent, and thickness of outwash materials and the drainage areas that contribute water to these areas. Each of these study areas contains a separate and identifiable ground-water reservoir which was appraised as to: (1) the size of the ground-water reservoir, (2) the quantity of water available for replenishing the reservoir, (3) the magnitude of ground-water development as of 1957, and (4) the possible conflict between established water uses and possible future large-scale ground-water withdrawals. Of the areas evaluated, eight were recommended as warranting detailed studies to determine the magnitudes of their available ground-water supplies. The areas recommended are listed in the order in which they are suggested for study as follows: the upper Pawcatuck River basin in the south; the Blackstone River area, the Pawtucket-East Providence area, and the Providence-Warwick area in the northeast; the Potowomut-Wickford area and the South Branch Pawtuxet River area in the central part of the State; and the Wood-Pawcatuck area and the lower Pawcatuck River area in the southwest.

INTRODUCTION

PURPOSE AND SCOPE

The United States Geological Survey, currently in cooperation with the Rhode Island Water Resources Coordinating Board and previously with the Development Council, the Port and Industrial Development Commission, and the Industrial Commission, has carried on a continuing program of investigations of the ground-water resources of the State since 1944. The results of these investigations are presented in a series of geological bulletins describing the ground-water resources of the State. These are reconnaissance-type reports, based largely on inventories of well and boring data and geologic field studies of rock outcrops and glacial deposits. To make such data available in a more concise form it was decided in 1958 to publish a series of ground-water maps using the U. S. Geological Survey 7½-minute topographic maps as a base. (See list of reports and maps, back cover.) This report presents the results of an overall appraisal of the ground-water reservoirs in 17 ground-water study areas in Rhode Island, based on information available through July 1957, and recommends the study areas that should be investigated in more detail.

The areas are generally evaluated as to: (1) the size of the ground-water reservoir, (2) the quantity of water available for replenishing the reservoir, (3) the present development of the water resources in the area, and (4) the possible conflict between established water uses and possible future large-scale ground-water withdrawals. Those areas which appear to have substantial ground-water reserves warrant more detailed investigations to determine the magnitude of their available ground-water supplies.

The study described in this report was made under the general direction of T. A. Monahan, former Executive Director, Rhode Island Development Council; Walter J. Shea, Chairman, Rhode Island Water Resources Coordinating Board; and A. N. Sayre, former chief, Ground Water Branch, U. S. Geological Survey; and under the supervision of J. E. Upson and G. C. Taylor, Jr., former district geologists, U. S. Geological Survey. W. B. Allen, W. H. Bierschenk, and G. W. Hahn, geologists, U. S. Geological Survey assisted the author in determining bedrock depths and thicknesses of unconsolidated sediments and compiled data on the geology and ground water in the bedrock and the unconsolidated deposits of the area.

ACKNOWLEDGMENTS

The cooperation of the following agencies and companies that furnished data used in the preparation of this report is gratefully acknowledged: Providence Water Supply Board, Bristol Water Co., Westerly Water Department, Woonsocket Department of Public Works, Pawtucket City Engineer, Newport Water Department, University of Rhode Island, and the U. S. Weather Bureau.

TOPOGRAPHY AND DRAINAGE

Rhode Island is composed of 11 cities and 28 towns. In general the towns comprise the rural areas of the State. They have a municipal government of less complex character than a city and have their sovereignty vested in a town meeting. In the towns are a number of villages which are small groups of houses. The cities are incorporated municipalities ranking higher in population than the towns. The locations of the cities and towns are indicated on plate 1. Some of the villages are used as references to locate important geologic and hydrologic features of the State.

Rhode Island lies in two major physiographic sections of the New England physiographic province. The northwestern third of the State, which consists of a hilly upland, is in the New England Upland section and the remainder, which contains several local subdivisions, is in the Seaboard Lowland section of the New England province. The boundary between the sections is based on differences in topography above and below altitudes of about 400 to 500 feet (Fenneman, 1938. p. 370). It extends northeastward from the Connecticut border north of the Exeter-Hopkinton town line, through Flat River Reservoir to the lower end of the Scituate Reservoir, thence north to the Massachusetts border (pl. 1).

The Seaboard Lowland section contains the Narragansett Basin, which includes much of the eastern part of the State and a low lying strip bordering the west shore of Narragansett Bay. To the west of the bay and adjoining the Atlantic Ocean are coastal lowlands, where the surface altitude is generally less than 200 feet. From a rather abrupt rise of about 200 feet to the west of Providence, the land surface rises gradually toward the hilly upland section in the northwestern part of the State.

Land-surface altitudes in the State range from sea level along the Atlantic Coast and around Narragansett Bay to 812 feet at Jerimoth Hill in the town of Foster. Surface altitudes are generally less than 400 feet in more than two-thirds of the State and less than 200 feet in about half the State.

Rhode Island is drained by a number of streams that discharge into Narragansett Bay or Block Island Sound. The streams that drain the north, central, and eastern parts of the State discharge into the bay, and the streams that drain the southern part of the State empty directly into Block Island Sound. About three-fourths of the land area of the State or almost 800 square miles is tributary to Narragansett Bay and about one-fourth to Block Island Sound.

The major streams of the State are: (1) the Branch, Blackstone, and Woonasquatucket Rivers in the north; (2) the Pawtuxet and Potowomut Rivers in the central part; (3) the Moosup River in the west; (4) the Tenmile and Warren Rivers in the east; and (5) the Pawcatuck and Saugatucket Rivers in the south. (See pl. 1.) Almost all of these streams are sources of municipal and (or) industrial water supplies.

Many of the streams of the State have their headwaters in the northwest uplands, where they occupy narrow, steep sloping valleys. In the lowlands, these streams generally are sluggish and meandering; and in the vicinity of the bay or ocean, they form fairly wide tidal estuaries.

CLIMATE

The climate of Rhode Island is greatly affected by the Narragansett Bay, which occupies much of the central and eastern parts of the State, and the Atlantic Ocean, which lies south of the State. These large bodies of water temper the climate so that periods of extreme hot or cold weather are generally infrequent and of short duration.

A study of Rhode Island weather (Harris and Odland, 1948) for the 10-year period 1937-1946, showed that the average annual temperatures for eight stations located throughout the State differed by only about 3°F. Therefore, the data collected by the U. S. Weather Bureau at the Theodore Francis Green Airport at Hillsgrove, R. I. are considered herein to be representative of average conditions in the State. Temperature data collected for the period 1905-1955 indicate that the mean annual temperature is a little over 50°F. The average annual temperature has ranged from 47°F in 1917 to 54°F in 1949. February is generally the coldest month having a mean of 29°F, and July is the hottest month having a mean of 73°F. The average temperature for February has ranged from a low of 17°F in 1934, to a high of 36°F in 1949; the average temperature for July has ranged from 68°F in 1914 to 78°F in 1952. Although February is the coldest month, January is almost as cold; likewise, in summer, August is nearly as hot as July.

Precipitation differs more widely between localities than does the temperature. Therefore, precipitation data for 22 stations in and near Rhode Island were collected and analyzed (table 1). The distribution of precipitation in the State is shown in figure 1.

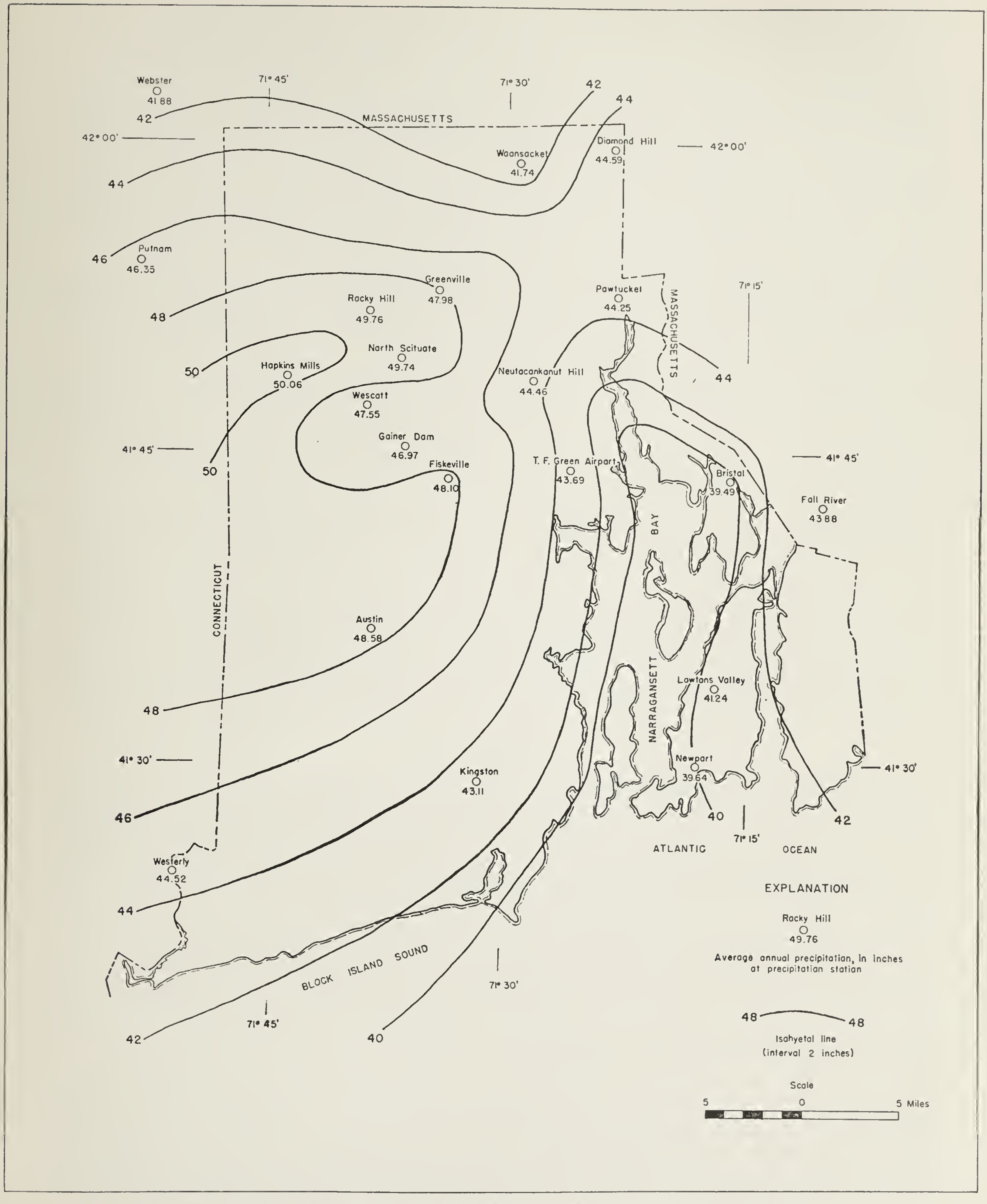

Figure 1.—Average annual precipitation in Rhode Island, 1940-1956.

Table 1.—Average monthly and annual precipitation in inches, 1940-1956

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Austin	4.00	4.01	4.80	3.81	4.33	2.75	3.34	4.87	3.20	3.81	5.50	4.16	48.58
Block Island	3.78	3.22	3.87	3.52	3.19	1.99	2.57	3.96	2.15	2.71	4.40	3.64	39.00
Bristol	3.30	3.07	3.46	3.25	3.69	2.15	3.08	4.04	2.91	2.81	4.49	3.24	39.49
Diamond Hill	3.95	3.32	4.23	3.75	3.76	2.83	3.42	4.35	3.30	3.17	4.77	3.74	44.59
Fall River, Mass.	3.90	3.48	4.26	3.48	3.72	2.54	3.16	4.84	2.76	2.95	4.90	3.86	43.88
Fiskeville	3.87	3.98	4.72	4.10	3.92	3.12	3.07	4.45	3.31	3.63	5.58	4.34	48.10
Gainer Dam	3.92	3.66	4.52	3.94	3.56	2.87	3.08	4.73	3.39	3.59	5.51	4.17	46.97
T. F. Green Airport	3.89	3.46	4.34	3.70	3.66	2.55	2.90	4.30	2.90	3.10	5.02	3.90	43.69
Greenville	3.38	3.16	4.35	3.98	4.41	3.52	3.36	4.70	3.60	3.64	5.97	3.92	47.98
Hopkins Mills	4.37	4.10	4.75	3.97	4.06	3.19	3.40	4.90	3.51	3.56	5.65	4.60	50.06
Kingston	3.75	3.28	4.16	3.48	3.77	2.40	2.90	4.65	2.76	3.03	5.14	3.76	43.11
Lawtons Valley	3.84	2.94	3.61	3.62	3.42	2.29	2.66	4.75	2.41	2.96	5.07	3.66	41.24
Neutaconkanut Hill	3.51	3.31	4.10	3.87	3.76	3.06	3.13	4.21	3.33	3.42	5.10	3.66	44.46
Newport	3.79	3.08	3.92	3.57	3.23	1.89	2.51	4.48	2.33	2.73	4.56	3.54	39.64
North Scituate	4.03	3.85	4.66	4.30	3.96	3.29	3.26	4.91	3.44	3.78	5.95	4.29	49.74
Pawtucket	3.86	3.38	4.17	3.72	3.99	3.13	3.10	4.16	3.23	3.28	4.71	3.56	44.25
Putnam, Conn.	3.40	3.04	4.19	4.01	4.08	3.56	3.74	4.70	3.58	3.14	5.19	3.72	46.35
Rocky Hill	3.84	3.91	4.52	3.99	4.12	3.68	3.42	5.14	3.49	3.68	5.77	4.19	49.76
Webster, Mass.	3.24	3.10	4.00	3.59	3.57	3.31	3.17	4.07	3.07	2.83	4.51	3.42	41.88
Westcott	3.87	3.78	4.49	4.10	3.74	3.05	3.22	4.69	3.28	3.52	5.69	4.11	47.55
Westerly	3.87	3.32	4.44	3.87	3.60	2.02	3.10	5.15	2.96	3.06	5.20	3.93	44.52
Woonsocket	3.41	2.99	4.11	3.31	3.42	2.96	3.16	4.26	3.23	2.89	4.30	3.70	41.74
Average of all stations	3.76	3.43	4.26	3.77	3.77	2.83	3.12	4.55	3.10	3.24	5.14	3.87	44.84

To present a uniform length of record for all stations, the data have been computed for the period, 1940-1956. The average annual precipitation for the State is a little less than 45 inches, ranging from 39 inches at Block Island to a little over 50 inches at Hopkins Mills in the northwestern part of the State. At all stations, the precipitation is fairly evenly distributed throughout the year. November is generally the wettest month having a mean precipitation of 5.14 inches, and June is the driest month having 2.83 inches. The average precipitation during November ranges from 4.30 inches at Woonsocket to 5.97 inches at Greenville; the range for June is from 1.89 inches at Newport to 3.68 inches at Rocky Hill.

HYDROLOGY

All fresh water available for human use is derived from precipitation. However, only a part of the precipitation that reaches the land surface eventually finds its way into either underground reservoirs or bodies of surface water. The remainder is returned to the atmosphere by evaporation and transpiration by plants, termed collectively "evapotranspiration". Under natural conditions and with no development of water supply for human use, the ground-water body of an area is in approximate equilibrium so that over a long period the recharge is equal to the discharge. Therefore, a volume of water equivalent to that which enters the area as precipitation leaves as surface or subsurface flow or as evapotranspiration.

In much of Rhode Island, the ground-water resources are undeveloped, and ground water is discharged into streams almost continually and maintains their dry-weather flow. A substantial part of streamflow is thus derived from ground-water discharge. The rate of ground-water discharge, however, is not constant but varies with changes in hydraulic gradient between the stream and the adjacent ground-water aquifer. Generally the discharge is greatest in the spring when the water table is at its highest level and least at the end of the summer or beginning of fall when the water table is at its lowest level.

In a closed basin, having no subsurface inflow or outflow, the water supply available for use over a long period of time is equal to the precipitation less evapotranspiration. However, evapotranspiration can be only partly reduced and water losses of substantial magnitude are inevitable. Although a uniform loss may be assumed to take place over a particular period, such water losses vary during a year and over longer periods, depending on such factors as: (1) the density of vegetal cover; (2) the type of vegetation; (3) the depth to the water table; (4) the areal extent of exposed water surfaces; and (5) climatic conditions in the area. Because evapotranspiration represents a net water loss, the runoff from a basin—the difference between precipitation and evapotranspiration—is indicative of the water supply that may be developed from surface sources without depleting the ground water in storage.

Much of the surface-water supply of an area can be utilized by the proper development of its ground-water resources. Artificial lowering of the ground-water level makes available additional underground storage for water that would normally be discharged from the area. This is especially true in the vicinity of a stream where the lowering of the ground-water level may reverse the normal hydraulic gradient and, thus, induce surface water to move into the aquifer. However, the rate at which water can be induced to flow into an aquifer is dependent not only upon the hydraulic gradient, but also upon hydraulic continuity between the stream and aquifer, and the permeability of the material in the stream bed and the aquifer. Under favorable conditions, it is possible to capture much or all of the dry-weather flow of a stream by placing a sufficient number of wells near and parallel to the stream.

Inasmuch as the streamflow is indicative of the potential perennial water supply of an area, stream-discharge data may be used to estimate the water supply that might be developed through ground-water installations. The major streams in Rhode Island are gaged by the U. S. Geological Survey. Kinnison (in Allen, 1953) presents a summary of the discharge records collected through water year 1950 and includes a table showing the discharge-duration relationships for the streams gaged. The data are useful in indicating (1) the effectiveness of the ground-water reservoir in storing and subsequently releasing water to the stream and (2) the quantity of water that is in the stream much of the time, part of which might be diverted into the underground reservoir by the use of wells. In an area in which the ground-water reservoir is comprised of highly permeable material, the underground reservoir regulates the stream flow and helps to maintain the flow at a relatively high and uniform level.

Results of detailed analysis of hydrographs for the Pawcatuck River made for a report on the ground-water resources of the Kingston quadrangle (Bierschenk, 1955) show that much of the flow in the river is derived from the ground-water reservoir and that the ground-water contribution is equivalent almost to the median flow of the river. Thus if it can be assumed that the same relation holds in areas where the geology is similar to that in the Pawcatuck basin, the median flow may be used to estimate the amount of ground water available in those areas. In all areas the median flow indicates the quantity of water in the stream much of the time, a part of which may be induced to replenish the ground-water reservoir.

GEOLOGY

The rocks in the upper part of the earth's crust contain numerous voids which store large quantities of water. However, there are many kinds of rocks and they differ greatly in the number, size, shape, and arrangements of their voids and, therefore, in their ability to store and transmit water. The character, distribution, and structure of the rocks has an important bearing on the occurrence and availability of ground water in an area.

A number of reports describe the geology of Rhode Island; many of these are listed in the bibliography of geology prepared by Quinn and Swann (1950). A general description of the water-bearing properties of the formations in the State was prepared by Allen (1953) and detailed discussions of the properties of the formations in various quadrangles in the State are presented by Allen (1948, 1950, 1951, 1953, 1956) and Bierschenk (1954, 1956).

The bedrock formations in Rhode Island are almost everywhere mantled by deposits of glacial till and outwash. In most parts of the State, the till occurs as a veneer over the surface of the underlying bedrock and is generally about 20 feet thick. The outwash mantles lowland areas and fills preglacial stream channels. In the north and northwestern parts of the State, the outwash occupies the central parts of the valleys and thus only partly fills the preglacial channels; whereas, in the lowlands bordering Narragansett Bay and in the valleys of the major rivers in the central and southern parts of the State, the outwash generally fills and conceals the preglacial channels. The outwash varies greatly in thickness, but in general is thickest in the buried channels.

For the purposes of this report, the geologic units are divided into two major groups according to their water-bearing properties; (1) outwash and (2) till, including mixed deposits of till and outwash, and bedrock (plate 1).

Water is stored in and transmitted through the openings between the rock fragments comprising the till and outwash deposits. The usefulness of these deposits as sources of ground water is dependent upon their porosity, specific yield, and transmissibility. Porosity, which is a measure of the proportion of a rock that is occupied by voids, is expressed as a percentage of the total volume of material. The specific yield is the quantity of water yielded by gravity drainage from a unit volume of saturated material and is likewise expressed as a percentage of the total volume of material. The specific yield is always less than the porosity, because some water is held in the openings by molecular attraction. The quantity of water retained per unit volume of material against the pull of gravity is termed specific retention, and is also expressed as a percentage. The sum of the specific yield and the specific retention of a saturated material is equal to its porosity. Transmissibility, which is a measure of the ability of a formation to transmit water from areas of recharge to areas of discharge, is defined as the flow of water in gallons per day, at the prevailing temperature, through a vertical strip of the aquifer one foot wide and extending the full saturated height of the aquifer under a hydraulic gradient of 100 per cent.

Although till and outwash are of comparable porosity, they differ greatly in transmissibility and specific yield; therefore, wells tapping these deposits also differ greatly in yield. Because the till deposits are poorly sorted and fine grained, they yield water slowly. Much of the water stored is held by molecular attraction and is not available for recovery. The specific yield of till is in the order of 1 per cent. This means that one square mile of till will yield by gravity about two million gallons of water per foot of saturated thickness. On the other hand, the many lenses of well-sorted sand and gravel in the outwash yield water freely to wells. The specific yield of outwash generally is much higher than that of till, but it may vary considerably locally. It ranges from about 1 per cent, in the poorly sorted or fine-grained outwash, to as much as 20 per cent, in well-sorted, coarse materials. Therefore, much more water is available to wells per foot of saturated thickness from outwash deposits than from till.

GROUND-WATER CONDITIONS IN GROUND-WATER STUDY AREAS

With respect to large ground-water developments, the till and bedrock formations of Rhode Island are not of great importance because they are not capable of yielding large quantities of water to individual wells. However, because of their wide occurrence and their ability to supply water in sufficient quantities for domestic and general farm purposes, they are used extensively in the rural areas of the State. The areas of greatest potential development of ground water are those in which extensive deposits of outwash are present. Large quantities of water of excellent quality are now obtained from wells tapping the outwash. However, only a part of the available water supply in these deposits has been developed and substantial additional supplies of water can be obtained.

In this report the State has been divided into 17 ground-water study areas (including Block Island) that form separate and identifiable ground-water reservoirs. The subdivisions were based on the occurrence, extent, and thickness of outwash deposits and on the extent of the drainage areas that contribute recharge to these ground-water reservoirs. As used in this report, a ground-water reservoir refers to the water-bearing formations present within each study area. Inasmuch as the water table in an area is continuous across geologic contacts, each study area is assumed to contain one extensive ground-water reservoir. The area boundaries were delineated on the basis of geology and surface topography. Because the bodies of outwash generally occupy the central parts of the present-day stream valleys or fill and conceal preglacial valleys, the boundaries of the ground-water reservoir areas follow highs in the bedrock surface, which tend to restrict the thickness of the water-bearing deposits and (or) limit the areal extent of the reservoirs, and thus effectively divide the State into identifiable ground-water units; however, those units along the periphery of the State that extend into either Connecticut or Massachusetts have as boundaries the State lines. These ground-water reservoir areas and their extent are indicated in plate 1. The location and extent of each of these areas, and the geology, occurrence of ground water, and estimates of water available in each are described in the following sections (p. 6-35).

UPPER BRANCH RIVER AREA

The upper part of the drainage basin of the Branch River includes an area of about 75 square miles, of which about 59 square miles is in Rhode Island and about 16 square miles in Massachusetts. The main tributaries of the Branch River, the Pascoag and Chepachet Rivers, which head in the southwestern part of the basin, flow northeastward and join near the village of Oakland in the east-central section of the Rhode Island part of the basin (pl. 2). The Branch River continues northeast and empties into the Blackstone River west of the city of Woonsocket.

The upper Branch River ground-water study area of this report includes the drainage basin of the Branch River upstream from Mohegan in Rhode Island. The area is highly irregular in shape, extending west of Mohegan about eight miles; its maximum width is about 10 miles north-south. The area is in the New England upland section of the New England physiographic province (pl. 1), where the topography is quite hilly and is characterized by fairly steeply-sloping hillsides. Durfee Hill, on the southwestern border of the Branch River drainage area, the highest point in the area, has an altitude of 804 feet; the lowest point in the area, altitude about 275 feet, is at Mohegan where the Branch River leaves the area.

The population of the area was about 11,000 in 1955; the largest concentration of population is in the Pascoag-Harrisville vicinity. There are no public ground-water supplies in the town of Glocester; however, there are nine public supplies in the town of Burrillville, two of which are municipally owned and the others privately owned. The two municipal supplies, those of the Pascoag and Harrisville Fire Districts, furnish water to about 3,600 persons of an estimated 5,000, served by public supplies. The average consumption of ground water for public supply is estimated to be about one mgd (million gallons per day). Much of the water pumped by the privately owned systems is used for sanitary purposes in industrial plants, but almost all of the water for industrial needs is obtained from surface sources. In addition to ground water pumped for public supplies, about 0.5 mgd is used for domestic and stock purposes. Accordingly, the overall withdrawal of ground water in upper Branch River area is estimated to be about 1.5 mgd.

Geology and Ground Water

About 16 per cent of the upper Branch River area is mantled by outwash which fills preglacial bedrock channels. The more extensive bodies of outwash are in the valleys of the Pascoag and Chepachet Rivers, and of the main stem of the Branch River. In the Pascoag River valley, the outwash fills a channel in the bedrock that extends northward from beneath the Pascoag Reservoir to Bridgeton, thence eastward to Oakland. Here the channel is joined by a partly buried channel of the Chepachet River valley, which trends northeastward from the Smith and Sayles Reservoir to this point. From the confluence of these bedrock channels, the outwash-filled bedrock channel of the main stem of the Branch River extends northeastward to a point northwest of Mohegan, where it swings eastward, passes through a narrow gorge at Mohegan, and continues to the southern end of the Slatersville Reservoir east of Nasonville. As indicated on plate 2, the eastern boundary of the area is at the bedrock gorge which interrupts the continuity and areal extent of the outwash in the Branch River valley.

The outwash deposits are thin at the heads and sides of these valleys, but thicken toward the axes of the bedrock channels and downstream. Known thicknesses of outwash range from 46 feet near Bridgeton and 50 feet at Harrisville to 61 feet northeast of Oakland. The relatively extensive outwash tract in the Bridgeton-Oakland area forms the principal part of the ground-water reservoir in the upper Branch River area. Outwash deposits in tributary valleys, which are less extensive than those in the Pascoag, Chepachet, and main Branch River valleys, are generally less than 20 feet thick.

Except for the relatively few public supply wells, the wells in the basin are used mainly for domestic and stock supply. The majority of these wells tap the bedrock and generally yield in the order of 5 to 10 gpm (gallons per minute); however, a yield as high as 70 gpm has been recorded from a well tapping the bedrock. The maximum recorded well yield for the upper Branch River area is that of a gravel-packed well that taps the outwash, owned by the Pascoag Fire District, which has a capacity of 350 gpm. A second gravel-packed well owned by the Pascoag Fire District was reported to yield 156 gpm. Another well tapping outwash, owned by the Harrisville Fire District, has a reported yield of 160 gpm.

Ground water in the upper Branch River area occurs under water-table conditions—that is, the upper surface of the zone of saturation is unconfined and the zone is recharged by the direct percolation of water from precipitation. The depth to water in the outwash generally is less than 10 feet. Because the outwash deposits occupy the low, central parts of the river valleys, the outwash receives recharge directly by percolation of precipitation, by seepage from the streams, and by underflow from adjacent areas of till and bedrock.

The gross ground-water storage capacity of the rocks in the upper Branch River area undoubtedly is large. However, the usable storage capacity, which represents the storage that can be utilized effectively, is only a small part of the gross storage capacity. The volume of water stored in the till deposits is large because of the widespread occurrence of till in the basin; however, because of the low permeability of the till, the storage capacity can not be used effectively. However, the usable ground-water storage capacity of the outwash in the Bridgeton-Oakland area is estimated to be in excess of one billion gallons.

Estimate of Water Available

The major part of the ground-water reservoir of the upper Branch River area underlies about 3 square miles in which moderately thick and permeable deposits of outwash are present. Less than 1 mgd was being withdrawn from it as of 1957. It is estimated that the outwash in this part of the area is replenished directly by precipitation at an average rate of 2 to 3 mgd. This represents only part of the water potentially available for development for in addition to local precipitation, water is also brought into the area by streams. The discharge of the Branch River is gaged by the Geological Survey at Forestdale about 4 miles downstream from Mohegan (pl. 3) The drainage area above the gaging station at Forestdale is about 93 square miles. Discharge-duration data presented by Kinnison (in Allen, 1953) indicate that the median discharge of the river at Forestdale is about 1.1 cfs (cubic feet per second) per square mile of drainage area. The part of the drainage area upstream from Oakland that overlies the principal part of the ground-water reservoir includes about 45 square miles. Assuming that the water yield of the basin is uniform, it is estimated that the median discharge of the Pascoag River at Oakland is about 50 cfs or about 32 mgd. The Chepachet River drains an additional 20 square miles in the southeastern part of the basin above its confluence with the Pascoag River. Its median discharge is similarly estimated to be about 22 cfs or about 14 mgd. The total discharge to the Branch River from the Pascoag and Chepachet Rivers thus is roughly estimated to be about 46 mgd.

Four sites in the upper Branch River basin on the Chepachet, Nipmuc, and Clear Rivers, have been recommended for the construction of surface-water reservoirs (Maguire, 1952). These surface reservoirs would regulate the runoff from a total area of about 48 square miles—20 square miles in the Chepachet River valley by a dam at Mapleville and the enlargement of the dam at the Smith and Sayles Reservoir; 16 square miles in the Nipmuc River valley by a dam about 0.75 mile upstream from its confluence with the Pascoag River; and 12 square miles in the Clear River valley by a dam at about the same location as the present Wilson Reservoir dam. The areas that would be inundated by the reservoirs are underlain largely by till. The ground-water storage capacity of the principal outwash tract would remain unchanged. However, the inflow to the Bridgeton-Oakland area from surface streams would be reduced by the amount diverted from the surface reservoirs.

As indicated on page 7, the thickness of the outwash in the central part of the Pascoag River valley ranges from less than 50 feet at Bridgeton to about 60 feet at Oakland. However, the thickness diminishes in relatively short distances toward the sides of the valley. Moreover, records of existing wells show that the outwash in the principal part of the ground-water reservoir is capable of yielding only moderate supplies of water. Because of the moderate-yielding capability of the relatively thin outwash material, the upper Branch River area is not considered favorable for extensive ground-water development, and detailed studies are not recommended.

NORTH SMITHFIELD-WOONSOCKET AREA

The North Smithfield-Woonsocket area is in the northern part of the State along the Rhode Island-Massachusetts border (pl. 1). It has an area of about 40 square miles of which all but about 5 square miles in the southeast part is in the Branch and Blackstone River basins.

The Branch and Blackstone Rivers have a number of short tributaries that are entrenched in narrow steep-walled valleys. The intervalley regions are very hilly; the hills generally are aligned in a north-south direction. The general relief of the area is between 100 and 200 feet. The maximum relief is about 522 feet, as measured between the point where the Blackstone River leaves the area, about 105 feet altitude, and the highest point along the southwest boundary, Absalona Hill, about 627 feet.

The population of the area is about 60,000, mostly in the city of Woonsocket. Most of the residents of the town of North Smithfield live in several small villages in the Branch River valley, the largest of which is the village of Slatersville. The city of Woonsocket water supply is from surface reservoirs in the Blackstone River area. Several company housing developments in villages in the Branch River valley are supplied by privately owned ground-water supplies which pump a total of less than 0.1 mgd. Industries in Woonsocket use about 0.15 mgd of ground water; the domestic use of ground water in the area is small. The total ground-water usage in the North Smithfield-Woonsocket area is estimated to be about 0.3 mgd.

Geology and Ground Water

Glacial outwash deposits underlie about 18 of the 40 square miles in the North Smithfield-Woonsocket area. Well logs indicate that the deposits vary greatly in thickness from place to place, but are generally thicker and more extensive where they fill preglacial bedrock channels.

The outwash-filled bedrock channel of the Branch River valley enters the area at Mohegan (pl. 2) and extends eastward beneath the present-day stream to the southern end of the Slatersville Reservoir, where it swings northeast and passes east of the village of Slatersville. As shown on plate 3, the Branch River departs from the preglacial channel near Slatersville. Geologic data are lacking for the part of the area north of lat 42° N.; however, it is likely that the bedrock channel continues northeast to join the Blackstone drainage system. A second bedrock channel is present in the eastern part of the area extending from the southeast boundary of the area northeast to Woonsocket (pl. 3). Except for a 2-mile reach of the channel in the southeast which is in the drainage basin of the Woonasquatucket River, the channel is entirely in the Blackstone River drainage system.

The bedrock features, where they form effective barriers to ground-water movement in the various stream valleys, define the boundaries of the area. They are also of great importance because the principal parts of the ground-water reservoir are in the deeper sections of the outwash-filled bedrock channels. The most important part of the ground-water reservoir in the North Smithfield-Woonsocket area is in the buried channel of the Branch River valley southwest of Slatersville beneath and adjacent to the Slatersville Reservoirs. The thickest section of outwash is about 800 feet wide and 2 miles long. Although the buried channel in the eastern part of the area is more extensive than the channel in the Branch River valley, it is less important as a source of ground water because the deposits contain a considerable amount of fine-grained material. This is indicated by the results of a test drilling program undertaken for the city of Woonsocket by consulting engineers in 1954 as part of a study for development of a ground-water supply. Of a total of 15 sites tested in the city, only 2 were considered suitable for development; these were located on the flood plain of the Blackstone River in the central part of the city. Elsewhere in the North Smithfield-Woonsocket area, the outwash is relatively thin; generally it does not exceed 30 feet in thickness. A more complete discussion of the geology and water-bearing characteristics of the material in part of the area is given in reports by Allen (1950, 1951).

Data are available from only a few wells that tap the major outwash tract in the Branch River valley, but these indicate that the ground water occurs under water-table conditions and that the position of the water table is largely controlled by the levels of the Slatersville Reservoirs. Most wells in the area are shallow dug wells which generally yield less than 10 gpm. Therefore, no estimate can be made of possible yields from properly constructed wells.

Estimate of Water Available

Water in the North Smithfield-Woonsocket area is derived from local precipitation and from the upstream drainage areas of the Branch and Blackstone Rivers. The Branch River is gaged at Forestdale, about one mile east of Slatersville, where its drainage area is about 93 square miles. The Blackstone River is gaged at Woonsocket, about half a mile south of the Massachusetts state line. The gage at Woonsocket records the flow from a drainage area of 416 square miles which includes the Branch River basin. The main outwash tract in the Branch River valley is near Slatersville only a short distance upstream from the gaging station; consequently, almost the entire gaged discharge of the Branch River flows over this part of the ground-water reservoir. Well logs show that permeable outwash tracts in Woonsocket are downstream from the gaging station on the Blackstone River at Woonsocket, therefore, the entire gaged runoff of the Blackstone flows past these tracts. Discharge-duration data for the Branch and Blackstone Rivers presented by Kinnison (in Allen, 1953) indicate their median discharges to be about 1.10 and 1.15 cfs per square mile of drainage area, respectively. Thus, the median discharge for the Branch and Blackstone Rivers is about 66 mgd and 310 mgd, respectively.

As of 1957 almost the entire flow of the Branch River was used for generating electric power at several sites along the river. The largest development of electricity is at a textile mill in Slatersville. The average daily water requirement at this plant was more than 100 mgd, which is much more than the median discharge of the Branch River. Therefore, water stored in the Slatersville Reservoirs has to be released to meet water needs during much of the year. However, very little of this water is actually consumed in the generation of power for the textile mill and thus is available for use downstream in the Blackstone River valley.

The industrial utilization of surface water in Woonsocket in addition to that temporarily diverted for power is in the order of 4 mgd, which is less than 2 per cent of the median discharge of the Blackstone River. Therefore, a considerable amount of water is available for development. Although the drilling program for the city of Woonsocket located few sites suitable for ground-water installations, the program was not exhaustive and probably other suitable sites are available.

As described above, the bedrock channel of the Blackstone River in the eastern part of the area is filled mostly with fine-grained material; also the areal extent of the main outwash tract in the Branch River valley is small, less than 1 square mile. Replenishment to the outwash tract from precipitation is estimated to be less than 1 mgd. Thus, large ground-water withdrawals would be dependent upon recharge from bodies of surface water. The ground-water body apparently is interconnected with sources of surface-water recharge at few places in the area. Probably the most favorable of these is adjacent to the Branch River just east of Slatersville. However, even here the permeable body of outwash deposits is very narrow, thus, the site is suitable for only a few wells. The Blackstone River valley in Woonsocket is the only part of the area in which substantial ground-water supplies might be developed. Because there is a growing demand for water in Woonsocket, and because there are sites in the North Smithfield-Woonsocket area at which large quantities of water may be developed from wells, it is suggested that a quantitative study of the ground-water resources of this area be made by the city of Woonsocket.

BLACKSTONE RIVER AREA

The Blackstone River area has an areal extent of about 49 square miles in the northeastern part of the State (pl. 1). Except for the part in the southwest which is drained by the Moshassuck River, the area is drained by the Blackstone River and Abbott Run which join at Central Falls to form the Seekonk River. From the confluence of the streams, the Seekonk River flows south to the Providence River and Narragansett Bay. The Moshassuck River flows southeast and south approximately parallel to the Blackstone and Seekonk Rivers and empties into the Providence River (pl. 3).

The Blackstone River area is in the Narragansett Basin of the Seaboard Lowland section of the New England physiographic province (pl. 1). The surface topography consists largely of gently rolling hills generally less than 300 feet in altitude. The total relief of the area is about 540 feet, as measured between Beacon Pole Hill, altitude of 547 feet, about in the center of the northern boundary of the area, and the Seekonk River at Pawtucket. The general relief of the basin, however, is only 200 to 300 feet. The Blackstone River is entrenched in a narrow, steep-walled valley north of Lonsdale, which is in many places as much as 100 feet below the general surface level adjacent to the valley.

The population of the area is estimated to be about 65,000 mostly in the cities of Central Falls and Pawtucket, in the extreme southern part of the area.

The withdrawal of ground water in the Blackstone River area is estimated to be about 4.0 mgd of which about 2.5 mgd is used for public supplies. The largest user of ground water in the valley is the Pawtucket Water Co., which pumps about 2.0 mgd from several wells east of Scotts Pond. Most of the inhabitants of the area are supplied by the Pawtucket and Woonsocket Water Companies, which obtain their supplies largely from surface-water sources inside the area.

Geology and Ground Water

Most of the lower Blackstone River area is underlain by till, but bedrock is exposed in a number of places. Only about 14 square miles of the 49 square miles in the area is underlain by glacial outwash deposits. Much of the outwash is in the form of kame terraces, which border both sides of the Blackstone River and Abbott Run for almost the entire reaches between Woonsocket and Lonsdale, and the Pawtucket Reservoirs and Central Falls, respectively. In the Blackstone River valley, the outwash filling the central part of the valley is overlain by flood-plain and river-terrace alluvium. The alluvium generally occurs as bars or islands immediately adjacent to or in the present-day river.

The outwash deposits are confined to the preglacial bedrock valleys of the ancestral Blackstone River and Abbott Run. Kame terraces, which were formed during the glacial epoch when ice filled the central parts of the bedrock valleys, consist largely of sand and gravel deposited by streams that flowed between the ice and the valley walls. As the ice melted, additional outwash was deposited in the central parts of the valleys. Therefore, although the present day Blackstone River and Abbott Run follow their preglacial courses in the area, their channels overlie many feet of unconsolidated material.

Records of wells tapping the outwash deposits in the ancestral Blackstone Valley indicate that the materials vary greatly in thickness. The deposits thicken to the southeast from about 30 feet at the northern boundary at Woonsocket to more than 200 feet south of Lonsdale in the present-day Moshassuck valley. The channel underlies the present Blackstone River northwest of Lonsdale and trends south beneath the Moshassuck River in the southern part of the area. The outwash in the Abbott Run valley also thickens downstream ranging from less than 20 feet just south of the Pawtucket Reservoir to about 90 feet near Central Falls.

Well logs also indicate that the widths of the bedrock channels vary from place to place along the streams. At the Woonsocket-Cumberland line, the width of the ancestral Blackstone channel is about 600 feet. It widens to about 1,000 feet in the vicinity of Manville, but narrows to about 400 feet near Albion. Downstream from Albion, the width of the channel increases again and reaches a maximum of about 4,500 feet southeast of Lonsdale. South of this point the channel narrows again and passes through a narrow gorge at the southern boundary of the area south of the Pawtucket-Providence city line (pl. 3).

In the Abbott Run valley, the bedrock channel increases in width downstream from about 600 feet, south of the Pawtucket Reservoirs, to about 3,000 feet east of Valley Falls. The largest part of the Abbott Run valley is in Massachusetts. Accordingly, the major part of the ground-water reservoir in the Blackstone River area is in the buried channel of the ancestral Blackstone River as outlined on plate 3.

Except for the relatively few wells used for industrial and municipal supplies, the wells in the Blackstone River area are used mainly for domestic purposes. The majority of these are shallow dug wells that tap till and generally yield 5 to 10 gpm. Few wells have been developed in the outwash deposits. The maximum recorded well yield is that of a gravel-packed well owned by the Pawtucket Water Co., which has a capacity of 1,400 gpm. Another large-capacity well is that owned by the Owens-Corning Fiberglas Corp., which has a capacity of 650 gpm. This well is located on the flood plain along the east bank of the Blackstone River near Ashton. The depth to water beneath the kame terraces is as much as 30 or 40 feet, but in the outwash deposits adjacent to the streams the water table is generally shallow and fluctuates with changes in stream level. Except where the water table is affected by pumpage, it is generally above stream level and ground water moves toward and discharges into the streams. During floods, however, low-lying areas along the channels are inundated and this movement is reversed. In addition to the lateral movement of water into the streams, a small quantity of underflow takes place beneath the streams and in the same direction as the flow of the streams.

Because of the small areal extent of the glacial deposits in the Blackstone River valley northwest of Lonsdale, the storage capacity of the outwash tract in this part of the area is not large. Therefore, the sustained high yield of a well such as the one near Ashton depends upon the rate at which water is induced to flow into the aquifer from the Blackstone River. Although the capacity of the ground-water reservoir in this part of the area to store water is small, its water-yielding potential is large because of its hydraulic connection with the river. The part of the ground-water reservoir south of Lonsdale is capable of storing a large amount of water. The buried channel in this part of the area has an average width of about 2,500 feet (Allen, 1948) and is about 6 miles long; its areal extent is about 3 square miles. If the specific yield of the coarse outwash deposits is assumed to be 10 per cent (approximately half the value computed from pump-test data from the Providence-Warwick area), the effective ground-water storage capacity in the buried channel would total about 60 million gallons per foot of deposits. As indicated in plate 3, a large part of the reservoir is thicker than 100 feet; therefore, the effective ground-water storage capacity is in the order of several billion gallons.

Estimate of Water Available

The ground-water resources of the area are virtually undeveloped in that only about 4 mgd is used. The amount of water derived from rainfall on the area is estimated to be equivalent to about 100 mgd, much of which is disposed of by direct runoff and evapotranspiration. It is estimated that about 14 mgd is potentially available from precipitation to recharge the principal part of the ground-water reservoir in the central and southern parts of the area.

In areas underlain by outwash there is little if any direct runoff. Thus, the part of the precipitation that is not lost by evapotranspiration is available to percolate to the water table. Precipitation is equivalent to about 2 mgd per square mile of which evapotranspiration accounts for about 1 mgd, leaving 1 mgd per square mile for percolation. The area of the principal outwash tract is 14 square miles, therefore, 14 mgd is potentially available.

In addition to rainfall, large quantities of water are brought into the area by the Blackstone River from its upstream drainage area. Stream discharge records from the gaging station at Woonsocket (Kinnison in Allen 1953) indicate that the median flow into the area during the period, 1930-1950, was about 1.15 cfs per square mile or about 310 mgd. Therefore, the median water supply in the area is about 410 mgd. At the present time about 35 mgd of surface water is used in the area in addition to 4 mgd of ground water. Of this amount about 12 mgd is diverted from the Pawtucket Reservoirs on Abbott Run, about 22 mgd from the main stem or tributaries of the Blackstone River, and less than 1 mgd in the Moshassuck valley. However, little of this water is actually consumed and except for the water pumped by the Pawtucket and Woonsocket Water Companies, the water is only temporarily diverted. For practical purposes, the available water supply is undiminished by present developments in the area. Although it is not feasible to utilize all this water, a substantial part of it may be recovered if properly constructed wells were put down in the outwash deposits adjacent to the Blackstone River and in the outwash deposits in the southern part of the area. A number of places within the area appear suitable for ground-water installations.

Because the ground-water supply is dependent to a large extent upon recharge from the Blackstone River, the quality of the water recharged is of great importance. Several chemical analyses of samples of Blackstone River water which were collected in 1951 indicate that the concentrations of most chemical constituents were generally within tolerable limits. However, objectionable amounts of iron were found (as much as 0.8 parts per million) and the water was slightly acid (ph 6.4). The quality of water in the Blackstone River is expected to improve as industrial users of the river water are being requested to cooperate in treating the effluents from their factories.

Because of the large amount of water potentially available, the Blackstone area, in particular, the principal part of the ground-water reservoir in the Blackstone and Moshassuck valleys, is recommended for quantitative investigation.

UPPER WOONASQUATUCKET RIVER AREA

The upper Woonasquatucket River area, in the north-central part of Rhode Island (pl. 1) has an area of about 23 square miles of which about 1.5 square miles in the extreme south is in the drainage basin of the Pocasset River and the remainder is in the Woonasquatucket River basin. The general relief in the area is 100 to 200 feet. The maximum relief is about 433 feet, as measured between the point where the Woonasquatucket River leaves the area, about 194 feet in altitude, and the highest point along the western boundary, Absalona Hill, about 627 feet altitude.

The population of the area is estimated to be about 4,000, the majority of whom dwell in the southern section of the area in and near Greenville. Two public water supplies, which have ground-water sources serve part of the population. The amount of ground water withdrawn for public supply is estimated to average less than 0.1 mgd. The quantity of ground water used in the basin for all purposes is in the order of 0.5 mgd.

Geology and Ground Water

An estimated 40 per cent of the upper Woonasquatucket River area is underlain by glacial outwash deposits. The deposits occur as fillings in bedrock channels; however, the channels are only partly filled. The outwash occurs in two places; (1) in the Stillwater River valley north of Waterman Reservoir in the western part of the area, and (2) in the upper reaches of the Woonasquatucket and Pocasset Rivers in the eastern part of the area (pl. 3). The outwash body in the Stillwater River valley is considered to be unimportant from the standpoint of available ground water because it is generally narrow and thin. Well logs indicate that in many places the deposit is less than 1,000 feet wide and 20 feet thick. In the other area outwash deposits of varied thickness are found along the Woonasquatucket River, except in the short reach east of the Woonasquatucket Reservoir, where the river flows through the narrow steep-walled gap.

The deposits extend south beneath the Woonasquatucket Reservoir and beyond the drainage divide between the Woonasquatucket and Pocasset Rivers into the Pocasset River valley. This outwash deposit extends the entire length of the area and is continuous with the outwash bodies to the north and south. The area boundaries were defined on the basis of bedrock features that form effective ground-water barriers. The northern boundary of the area in the Woonasquatucket River valley was determined from well logs which show the presence of a bedrock saddle north of Smithfield. In the Pocasset River valley, the southern boundary is located from a map of the surficial geology of the area, which shows a number of bedrock outcrops. These indicate that a bedrock saddle may be present, which would form an effective ground-water barrier.

The extensive body of outwash that constitutes the principal part of the ground-water reservoir in the area varies considerably in width and thickness. It is narrowest and thinnest at the bedrock saddle along the northern boundary (south of the Smithfield-North Smithfield town line, pl. 3), where it is less than 1,000 feet wide and about 10 to 20 feet thick. The outwash body increases in width and thickness to the south and, along Putnam Pike, it is about 1.5 miles wide and is more than 60 feet thick in places. The exact extent of the channel is not known because of the lack of geologic data in the southern part of the ground-water study area. However, it is likely that the channel is present beneath Reaper Brook and in the vicinity of Slack Reservoir and Hawkins Pond.

Ground water occurs under unconfined conditions throughout the area. The depth to the water table ranges from 5 to 30 feet; the greatest depths are on the summits or slopes of hills and the lesser depths are in the lowlands or in the vicinity of bodies of surface water. The ground-water storage capacity of the outwash is not large, because the outwash is generally thin and of small lateral extent.

Estimate of Water Available

The amount of water derived from precipitation on the upper Woonasquatucket River area is estimated to be equivalent to about 50 mgd. On the basis of precipitation and runoff data, about half of this water is lost to evapotranspiration. Nearly all of the remainder finds its way into the surface streams and leaves the area via the Pocasset and Woonasquatucket Rivers. In addition to the water derived from precipitation, it is estimated that about 4 mgd is brought into the area by the Woonasquatucket River from its upstream drainage area.

As indicated on plate 3, except for the small part of the area in the Pocasset drainage basin, all of the area drains into the Woonasquatucket Reservoir. The discharge of the Woonasquatucket River is gaged at Centerdale, about 5 miles downstream from the Woonasquatucket Reservoir. Discharge-duration data for the stream (Kinnison in Allen, 1953) show that the median flow is equivalent to about 1.2 cfs per square mile. The drainage area of the reservoir is about 25.5 square miles, therefore, assuming the yield of the basin to be uniform the median inflow into the reservoir is about 31 cfs or 20 mgd.

The Woonasquatucket reservoir is owned and operated by the Woonasquatucket Reservoir Co. which was formed by the industrial water users of the Lower Woonasquatucket Valley to assure an adequate water supply in all seasons of the year. As of 1957, about 18.5 mgd of surface water was used downstream from the reservoir. To insure that an adequate water supply is available for use of the Reservoir Co. members, a minimum flow of about 20 mgd is maintained in the downstream part of the river.[1]

The principal part of the ground-water reservoir in the area extends south of the Woonasquatucket Reservoir. As indicated on page 12, the thickness of the outwash aquifer varies greatly but much of it is considerably less than 50 feet thick. The part of the aquifer that is more than 50 feet thick has an areal extent of less than 3 square miles. Recharge to the ground-water reservoir from precipitation is about 2 to 3 mgd. As shown on plate 3, the study area is very narrow and elongated; hence, the movement of ground water in it is largely into the surface stream.

The more favorable sites for the development of ground-water supplies are in the southern part of the area where the ground-water reservoir is hydraulically connected with bodies of surface water. However, because the coarse water-bearing zone is small in extent and generally thin, it has little ground-water storage capacity. If the materials are only moderately permeable, then large-yield wells cannot be developed. For those reasons, the upper Woonasquatucket River area does not warrant extensive quantitative study.

PROVIDENCE-WARWICK AREA

The Providence-Warwick area is in the northeastern part of the State and is approximately 114 square miles in extent. The eastern part of the area is in the Narragansett Basin of the Seaboard Lowland section of the New England physiographic province (pl. 1). Except for several isolated till-bedrock hills, this part of the area is a relatively flat plain whose surface altitude is generally lower than 50 feet. West of Providence, the land surface rises rather abruptly to about 200 feet and continues to rise gradually toward the hilly upland in the northwestern part of the State. The total relief of the area is about 560 feet; the altitude ranges from sea level along Narragansett Bay to about 560 feet at Pine Hill on the northwestern boundary about three-quarters of a mile south of Hartford Ave. (pl. 3). The area is drained by the Woonasquatucket and Pawtuxet Rivers, which empty into Narragansett Bay. In the eastern part of the area, the Pawtuxet River is the dividing line between the heavily populated and industrialized sections of Cranston and Providence to the north and the lesser developed part of Warwick to the south. (See pl. 3.)

The Providence-Warwick area is the most heavily populated in the State. The population was estimated to be about 410,000 as of 1955 of which about 90 per cent are in the cities of Providence, Cranston, and Warwick in the eastern part of the area. Almost the entire population is served by public water systems that have their sources outside the area. Nearly all water obtained within the area is used for industrial purposes.

The daily ground-water withdrawal in the Providence-Warwick area is estimated to be in the order of 8 mgd. Most of this amount is withdrawn from the part of the ground-water reservoir in the northeast in the sections of the cities of Providence and Cranston that lie between the Woonasquatucket and Pawtuxet Rivers.

Geology and Ground Water

About 57 of the 114 square miles in the Providence-Warwick area is underlain by glacial outwash deposits. Elongate deposits of outwash are present in the Woonasquatucket River and Pocasset River valleys, but the most extensive body of outwash occupies the entire eastern half of the area except where it is interrupted by small isolated till-bedrock hills which are bedrock highs capped by till (pl. 3). This extensive body of outwash constitutes the major part of the ground-water reservoir of the area. It has an areal extent of about 50 square miles. The outwash extends across several bedrock channels in which the thickness of the deposits locally exceeds 200 feet. With respect to accessibility and ground-water storage capacity, the most important of the buried channels is that of the ancestral Blackstone River which extends south from the northern boundary of the area, beneath Mashapaug Pond, to Greenwich Bay. As indicated on plate 3, the northern boundary crosses the buried channel at a constriction where the channel passes between two till-bedrock hills. The cross-sectional area of the channel at this constriction is so much less than on either side that the movement of water between the Blackstone River and Providence-Warwick areas is small.

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[1] Personal communication, A. W. Anderson, Engineer, Woonasquatucket Reservoir Co., August 6, 1957.

The outwash tract in the Woonasquatucket River valley is long and narrow and is hydraulically connected with the overlying surface stream. The outwash deposit increases in width and thickness downstream from about 800 feet and 20 feet, respectively, northwest of Stillwater, to about 2,000 feet and 45 feet, respectively, at Centerdale, and to about 1 mile and 100 feet respectively, in southwest Providence.

Information as to the width and thickness of the outwash in the Pocasset River valley is scanty. However, it is likely that the deposit is narrow and less than 50 feet thick. Outwash also fills bedrock channels tributary to the ancestral Blackstone channel.

The water in the major part of the ground-water reservoir of the Providence-Warwick area generally is unconfined. However, in the vicinity of Mashapaug Pond and Tongue Pond, lenses of impermeable material at shallow depths have created perched water tables. The perched table near Tongue Pond is about 20 feet above the main water table, which is at about 30 feet altitude. The impermeable material below the perched water body at Mashapaug Pond, moreover, caps underlying water-bearing material and produces confined or artesian conditions in the underlying deposits. Because the artesian head adjusts to the head in the adjacent unconfined deposits, the water levels in wells tapping the confined and unconfined parts of the reservoir are at comparable altitudes.

Data are lacking as to the extent and shape of the permeable outwash body. Therefore, an estimate of the total ground-water storage capacity of the principal part of the reservoir cannot be made. However, it is possible to estimate the usable storage capacity of a part of the reservoir. Present data indicate that much of the outwash comprising the principal part of the reservoir ranges in thickness from 50 feet to more than 100 feet (pl. 3). Eliminating those parts that are less than 50 feet thick, 35 square miles remain. Within much of this remaining area, the thickness of the outwash is more than 100 feet and for this it is not unreasonable to assume an average saturated thickness of about 50 feet. Thus, assuming a specific yield of 10 per cent, a conservative estimate of the available ground water in storage would be about 35 billion gallons. An even more important favorable characteristic of the outwash in the reservoir is its transmissibility. As indicated by the large capacity wells in the industrialized eastern section between the Woonasquatucket and Pawtuxet Rivers, the transmissibility is high. A large percentage of these wells are capable of yielding from 700 to 1,000 gpm.

Estimate of Water Available

Water enters the Providence-Warwick area as precipitation, and as streamflow in the Woonasquatucket and Pawtuxet Rivers and their tributaries. However, the streams are regulated by upstream surface reservoirs. As indicated in the discussion of the upper Woonasquatucket River area, the industrial water users in the Woonasquatucket River valley require a flow of about 18.5 mgd. This flow is maintained by releasing water from the Woonasquatucket Reservoir during low-flow periods. During a large part of the year the streamflow is only sufficient to meet the needs of the water users. However, because most of the diversions of water from the river are for non-consumptive uses much of the water is returned to the stream and is available to replenish the principal part of the ground-water reservoir downstream in the eastern part of the Providence-Warwick area. Similarly, although the waters of the Pawtuxet River are used to a great extent in its upstream reaches, the flow of the stream in the downstream reach is substantial and is available for replenishing the principal part of the ground-water reservoir.

The discharge of the Pawtuxet River is gaged at Cranston, about 0.7 mile upstream from its junction with the Pocasset River. The drainage area of the stream above the gaging station is about 200 square miles. Discharge-duration data (Kinnison in Allen, 1953) indicate that the median discharge is about 1.1 cfs per square mile or about 142 mgd (220 cfs). The median discharge of the Woonasquatucket River at Centerdale is about 1.2 cfs per square mile. Applying this value to the entire drainage area of the Woonasquatucket River upstream from the major ground-water reservoir, the median flow is estimated to be about 39 mgd. The Pocasset River also contributes water to the principal part of the ground-water reservoir. The river has a drainage area of about 20 square miles. No discharge data are available for the Pocasset River; however, the Pocasset basin is similar geologically and topographically to the Woonasquatucket basin. Thus, assuming the median discharge per square mile of the Pocasset River drainage area is about the same as that for the Woonasquatucket River basin, the median flow of the Pocasset River is estimated to be about 16 mgd. Allowing for upstream diversions by the city of Providence which is about 40 mgd, the median inflow of all the streams tributary to the principal part of the ground-water reservoir in the eastern half of the Providence-Warwick area is estimated to be about 160 mgd.

As of 1957, the principal body of outwash in the area was replenished largely by direct infiltration from local precipitation. The average annual precipitation in the Providence-Warwick area is about 44 inches, which is equivalent to about 2 mgd per square mile. The total areal extent of the major ground-water reservoir is about 50 square miles; thus, the average daily precipitation on the reservoir area is about 100 mgd. A large part of the precipitation is lost by evapotranspiration, and, in the built-up part of Providence and Cranston, much of the precipitation is collected and removed from the area in storm sewers. However, it is estimated that the natural replenishment to the ground-water reservoir is roughly 30 to 50 mgd.

Available water-utilization data indicate that about 27 mgd of surface water is used in the Providence-Warwick area. As described on page 14, 18.5 mgd is used in the Woonasquatucket Valley; about 8.5 mgd is used in the Pawtuxet Valley. However, these surface diversions are west of the principal body of permeable outwash in the area and are largely for non-consumptive use. Therefore, there would be little interference with established water uses if the important water-bearing outwash deposits were more extensively developed. Because the outwash is capable of storing and transmitting large quantities of water and because substantial amounts of water are available for replenishment, the Providence-Warwick area is suggested for detailed quantitative study.

PAWTUCKET-EAST PROVIDENCE AREA

The Pawtucket-East Providence area is in the northeastern part of the State and is approximately 17 square miles in extent. The area is in the Narragansett Basin of the Seaboard Lowland section of the New England physiographic province (pl. 1). Much of this and adjacent areas is a southward sloping plain at altitudes less than 100 feet. The plain is interrupted by an unnamed isolated hill along the western boundary that rises to an altitude of about 200 feet. The total relief of the area is about 200 feet; altitudes range from sea level along the lower reaches of the Providence and Seekonk Rivers to about 200 feet at the summit of the unnamed hill. The area is drained by several streams; the Seekonk River drains the western half of the area and empties into the Providence River, which discharges into the north end of Narragansett Bay; the Tenmile River drains the eastern part and empties into the Seekonk River. The southern part of the area drains directly into the Providence River.

The withdrawal of ground water in the Pawtucket-East Providence area is estimated to be about 3.0 mgd. Almost all of this water is used for public and industrial purposes. Because the population in the area is served almost entirely by municipal supplies, the use of ground water for domestic purposes is negligible. Industries account for about 1.2 mgd, and the remaining 1.8 mgd is withdrawn for the municipal supply of the city of East Providence. The Pawtucket Water Co. obtains its supply from wells and surface reservoirs in the Blackstone River area.

Geology and Ground Water

About 15 of the 17 square miles in the area are underlain by outwash deposits; the remaining 2 square miles are covered by till, through which bedrock crops out locally. The outwash fills and conceals a preglacial bedrock channel. The till occurs in two hills along the western and eastern borders of the area and also mantles a bedrock hill, which is surrounded by outwash, in the south-central part of the area.

The buried channel is in the preglacial valley of the ancestral Seekonk River. It originates in the extreme northern part of the area, in the vicinity of the Rhode Island-Massachusetts border, and extends southwest beneath the Seekonk River to the Providence-Warwick area. The channel is filled by stratified fine- to coarse-grained materials. Lenses of coarse sand and gravel of varying width and thickness are present. The depths and locations of these lenses are generally unpredictable, but where penetrated by wells they are excellent sources of ground water.

The thickness of the glacial deposits in the area varies considerably from place to place, but well logs indicate that the till is generally less than 20 feet thick. However, the outwash in the buried channel is generally more than 50 feet thick and in the central part of the channel is more than 100 feet thick. The maximum recorded thickness of outwash in the channel is about 150 feet at a well in the northern part of the area. Outside the buried channel the outwash is generally less than 50 feet thick. Because the principal part of the ground-water reservoir in the area is in the central part of the buried channel, the thinner deposits of outwash probably indicate the presence of bedrock highs which are effective in limiting the movement of ground water between areas. As indicated in plate 3, the bedrock highs form part of the area boundaries as well as topographic divides on the till-bedrock hills.

Ground water in the Pawtucket-East Providence area occurs almost everywhere under water-table conditions, although confined or artesian conditions have been observed locally, especially in the eastern part of the area adjacent to Central Pond. Logs of wells in the Central Pond area indicate that the artesian conditions are produced by fine-grained material, which overlies coarser grained material. However, because the artesian head adjusts to the head in the adjacent unconfined material, wells tapping the confined and unconfined parts of the aquifer have comparable water-level altitudes.

A number of wells drilled in the area penetrate the entire thickness of unconsolidated material and are finished in the underlying bedrock. Records indicate that depths to water in wells tapping bedrock are generally greater than in wells finished in outwash. The average depth to water for all wells in the area is about 30 feet; in wells tapping outwash, water levels are from 10 to 15 feet below the surface; and in wells tapping bedrock, they are from 10 to 69 feet below the surface.

The usable storage capacity of the ground-water reservoir in the Pawtucket-East Providence area is large. However, much of this capacity is in the buried channel, where the deposit is thickest. The outwash in other part of the area is relatively thin; hence, an estimate of the effective storage capacity is presented only for the buried channel, which constitutes the principal part of the reservoir. Because a thickness of outwash of about 150 feet was penetrated by a well in the channel, it is not unreasonable to assume a saturated thickness of 100 feet. The average width of the channel is estimated to be about 1,000 feet; and the linear extent of the channel about 3 miles. (The segment of the channel beneath the Seekonk River is not considered because it presumably contains salty water). Assuming a specific yield of 10 per cent, the volume of available ground water in storage is about 1 billion gallons.

More than 50 per cent of the ground water withdrawn in the area is from wells owned by the city of East Providence. The East Providence wells are on the west shore of Central Pond. Almost the total yield of the wells is derived from the induced flow of water from the surface-water body. Thus, very little of the ground water stored in the area has been drawn upon or developed, and the recharge to the outwash from precipitation is more than sufficient to compensate for the amount actually withdrawn.

Estimate of Water Available

Large quantities of water are brought into the Pawtucket-East Providence area by the Seekonk River. However, the river is tidal for its entire length within the area and contains salty water. Therefore, large withdrawals of water from the outwash adjacent to the river ultimately would result in the contamination of part of the reservoir by the encroachment of the salty water. Because of this, the parts of the area considered most suitable for ground-water development are in the north, where permeable outwash fills the buried channel, and in the east, where permeable materials lie adjacent to Central Pond.

The part of the ground-water reservoir in the buried channel is remote from the important streams that traverse the area and, therefore, is replenished largely by the percolation of water derived from local precipitation. The surface area that contributes such replenishment to the buried channel is estimated to be about 3 square miles. The average annual precipitation is about 44 inches or about 2 mgd per square mile. Because a large part of the land surface overlying the channel is paved and built-up, a considerable part of the precipitation runs off over the surface or is collected in storm sewers and removed from the area. In addition there are substantial losses by evapotranspiration. Nevertheless, the recharge to the outwash in the buried channel is estimated to be on the order of 2 to 3 mgd.

The outwash in the eastern part of the area is hydraulically connected with the Tenmile River. The wells tapping the aquifer in this area are located adjacent to the river, and it is likely that most of the ground water withdrawn is derived from the river. Runoff data for the Tenmile River are available only for the period 1923 through 1926. The measurements were made at Hunts Mills which is about half a mile downstream from the East Providence Reservoir. However, the reservoir was not in existence at the time the measurements were made. The average annual runoff of the river for the period of record is about 24 inches. This agrees with the figure indicated for the area by Knox and Nordenson (1955) in their diagram showing average annual runoff in the New York-New England area. The drainage area of the Tenmile River above Hunts Mills is about 56 square miles. One inch of water on the drainage area is equivalent to about 970 million gallons, therefore, the average annual runoff is about 23,000 million gallons, or, on an average daily basis, about 64 mgd.

According to available water-utilization data, the total amount of surface water used in the area is about 15 mgd which includes about 3 mgd from the East Providence Reservoir for the city supply. Much of this water use is non-consumptive. Therefore, a substantial amount of water remains available for development. Because of the large storage capacity of the ground-water reservoir in the area and the availability of substantial quantities of water for replenishing the reservoir, the Pawtucket-East Providence area is suitable for quantitative study.

BARRINGTON-WARREN AREA

The Barrington-Warren area is in northeast Rhode Island at the north end of Narragansett Bay (pl. 1). It has an area of about 20 square miles. The area is in the Narragansett Basin of the Seaboard Lowland section, where the surface altitude generally is less than 50 feet. The maximum relief in the area is about 150 feet, as measured between the highest point, the summit of a small hill on the northeast boundary at about 150 feet altitude, and the many miles of bay shoreline at sea level. As indicated in plate 3, the area is divided into several subareas by tidal streams which traverse the area. The main part includes the southern half of the city of East Providence and the western part of the town of Barrington. This part of the area is bounded on the east by the Runnins and Barrington Rivers and on the other sides by the Narragansett Bay. The eastern part of Barrington is a small peninsula bounded by the Barrington River on the west and the Warren River on the east. The southeastern part of the area includes Warren and the northern part of Bristol which are bounded and (or) traversed by the Warren and Kickamuit Rivers.

The population of the area in 1955 was estimated to be about 30,000; almost all of the inhabitants were in the west and south parts of the area. The city of East Providence has its own water supply, the source of which is in the Pawtucket-East Providence area. Barrington, Warren, and Bristol are supplied water by the Bristol County Water Co., which has a combined surface- and ground-water supply. The company obtains its surface supply from several reservoirs, one of which is on the Kickamuit River in Warren, and its ground water from a well field in south-central Barrington. Diversified industries in Barrington and Warren also have ground-water supplies. The total ground-water usage in the area is estimated to be about 2.0 mgd.

Geology and Ground Water

Except for several small isolated till-bedrock hills, the Barrington-Warren area is underlain by outwash deposits. Actually, outwash underlies about 17 of the 20 square miles in the area. The thicker and more extensive deposits fill and conceal a south-trending preglacial bedrock channel that extends beneath the western part of Barrington. A north tributary channel underlies the Runnins River valley and a northeast tributary channel is largely in Massachusetts in the Warren (Palmer) River valley (pl. 3).

The tidal streams that traverse the area effectively divide the outwash-filled channel into several ground-water units. The outwash in part of the main channel underlying the Barrington River and in the southern part of the north tributary channel in the Runnins River valley probably contains salt water. Consequently, the main ground-water unit in the area that is available for development is in the part of the buried channel that underlies Barrington.

The wells of the Bristol County Water Co. which tap the outwash-filled channel are in south-central Barrington and about 0.15 mile north of Nayatt Road and about 1.25 miles west of the Warren River. A report describing the ground-water resources of part of the Barrington-Warren area (Bierschenk, 1954) contains a northwest-southeast section and an east-west section, both through the water company well field. The sections show the general lithology and thickness of the materials comprising the part of the ground-water reservoir in this area. As shown, the materials vary considerably within comparatively short horizontal and vertical distances. North and west of the well field, the outwash consists largely of clay. At the well field, south and immediately east of it the outwash consists largely of sand and gravel. Clay and hardpan cap the water-bearing sand and gravel at the well field, but are not present south of the field. The effective thickness of the permeable outwash increases to the south, and the ground water, which is confined at the well field, is under water-table conditions elsewhere.

Existing wells tapping the ground-water reservoir are mostly shallow-dug wells. The only large-capacity wells in the area indicative of the ability of the principal part of the reservoir to transmit and yield water in substantial quantities to wells are the two owned by the Bristol County Water Co. Although these wells are pumped at a rate of about 1 mgd, their original tested yields indicate that they are capable of supplying a total of approximately 2 mgd.

Estimate of Water Available

The only sizable stream containing fresh water in the area is the Runnins River which forms part of the northeast boundary between Rhode Island and Massachusetts. The downstream tidal stretch of the river is named the Barrington River. The non-tidal Runnins River has a drainage area of about 9 square miles of which about 2 square miles are in Rhode Island. The average annual runoff for this part of the State as indicated by Knox and Nordenson (1955) is about 24 inches. One inch of water on the drainage area is equivalent to about 156 million gallons; thus, the average annual runoff is about 3,750 million gallons, or on an average daily basis, about 10 mgd.

Available water utilization data indicate that the surface-water usage in the Runnins River valley is about 4 mgd. This water is diverted only about three-quarters of a mile upstream from the tidal reach of the river and is returned to the river downstream from the point of withdrawal. Therefore, any upstream development, be it surface-water or ground-water, can only be of such a magnitude that it would not interfere with the established water users. Discharge-duration data for the various streams in the north and central parts of the State (Kinnison in Allen, 1953) indicate that the median stream discharge is about 1.2 cfs per square mile. For the Runnins River this would be equivalent to about 7 mgd; hence, though the average discharge of the river may be about 10 mgd, 50 per cent of the time the flow is probably less than 7 mgd. Thus, it is likely that during the low-flow period of the year (July to October) the streamflow is only sufficient to meet established needs.

Because the tidal streams that cross the buried channel in the southern part of the area contain salty water, the principal water-bearing sand in West Barrington is threatened by salt-water encroachment. The ultimate yield of this part of the reservoir is limited to the recharge derived from local precipitation; overdevelopment would result in the encroachment of salt water from the tidal streams and the contamination of the aquifer. The average annual precipitation on the area is about 40 inches which is equivalent to about 1.9 mgd per square mile. However, the amount of water available for replenishing the water-bearing sand is only a part of the total precipitation. As previously indicated, a section of the ground-water reservoir area in West Barrington is underlain by fine-grained deposits, therefore, much of the precipitation is lost to evapotranspiration and direct surface runoff. However, recharge to the permeable outwash is estimated to be about 2 to 3 mgd. Ground-water withdrawals are in the order of 2 mgd; thus it is evident that the safe yield of the outwash aquifer is being approached if it has not already been reached.

The Barrington-Warren area does not warrant quantitative study because of the limited extent of the part of the ground-water reservoir suitable for development and the relatively small amount of water available for replenishment. The water that is available should be reserved for the anticipated increase in the needs of established water users in the area.

QUINEBAUG RIVER AREA

The Quinebaug River is one of the major streams in Connecticut, but the headwaters of several of its tributaries lie in the extreme northwestern part of Rhode Island. The Moosup River and smaller tributaries drain about 61 square miles in Rhode Island. They flow southwestward to join the Quinebaug River.

Only the Rhode Island part of the Quinebaug River Basin (pl. 1) is referred to in the following discussion. The Quinebaug River area is about 24 miles long and ranges in width from about 0.75 mile in the central part to about 5 miles in the south. The area lies within the New England Upland section of the New England physiographic province (pl. 1). It is a hilly area drained by a number of small streams that have narrow, steep-walled valleys. The maximum relief in the area is about 470 feet. The highest point, Jerimoth Hill, about 0.4 mile south of the Glocester-Foster town line and about 0.75 mile east of the State line, has an altitude of 812 feet. The lowest point in the area, at about 340 feet altitude, is along the western border, where the Moosup River flows across the State line into Connecticut.

The population of the area is very small. The area lies in a remote part of the State, distant from centers of population and industrial activity, and removed from areas suitable for recreational exploitation.

Ground-water withdrawals in the area are very small, probably in the order of 25,000 gpd (gallons per day). There are few wells in the area and these are generally shallow dug wells used for domestic purposes.

Geology and Ground Water

It is estimated that only about 10 square miles or about 16 per cent of the Quinebaug River area is underlain by outwash deposits. The outwash is more or less confined to the southern part of the area in the central part of the Moosup River valley. Because few well records are available, the extent and thickness of the deposits in the Moosup valley are not presently known. However, it is likely that the outwash is too thin and areally inextensive to be considered an important ground-water unit. The remainder of the area is covered largely by till, and bedrock is exposed in some places.

The till is quite porous and contains a fairly large volume of water. However, because of the small interstices or voids between rock fragments, much of the water stored is held by molecular attraction and is not available for recovery. It is difficult to estimate the effective storage capacity of the till aquifers in the Quinebaug River area because of the lack of data. The thickness of the till in the basin varies greatly, but is believed to be generally less than 50 feet. However, one well in the north-central part of the basin penetrated 111 feet of till-like material before encountering bedrock.

Estimate of Water Available

Additional supplies of ground water in small quantities can be developed for domestic and general stock uses in the Quinebaug River area. However, the possibilities of developing large yields from wells in the area are small because of the low permeability of the till deposits. Moderate supplies of ground water may possibly be obtained from the outwash deposits in the Moosup River valley, but the yield of wells in this area would depend upon the thickness and permeability of the outwash and the rate at which water can be induced to flow into the aquifer from the Moosup River.

From a diagram showing average annual runoff in the New England-New York area (Knox and Nordenson, 1955) the average yearly discharge from the basin is estimated to be about 26 inches. On a drainage area of 61 square miles, one inch of water is equivalent to about 1,060 million gallons, and this multiplied by 26 would indicate that the total amount of water available is about 27,500 million gallons per year. On an average daily basis this is about 75 mgd. However, no important ground-water aquifers are present in the area; hence, quantitative investigations are not warranted in it.

NORTH BRANCH PAWTUXET RIVER BASIN

The North Branch Pawtuxet River basin lies in the northwestern part of Rhode Island (pl. 1). The topography of the basin is hilly, typical of the upland section of the New England psysiographic province (pl. 1). Altitudes range from 812 feet at Jerimoth Hill, along thé northwest surface divide of the basin, to about 90 feet, along the North Branch Pawtuxet River where it leaves the basin. The basin has an extent of about 105 square miles, of which about 7 square miles are covered by impounded water. Six impounding reservoirs in the basin have a combined usable storage capacity of more than 39 billion gallons and are the sources of supply for the city of Providence. The Providence water system also supplies all or parts of the cities of Cranston and Warwick and the towns of Johnston, North Providence, and Smithfield.

The population in the North Branch Pawtuxet River basin is estimated to be about 7,000; the largest concentration is in the village of North Scituate. There are no public or large industrial ground-water supplies within the basin. Ground water is used mainly for domestic purposes and is obtained largely from privately owned dug or drilled wells. Ground-water usage in the North Branch Pawtuxet River basin is estimated to be about 0.35 mgd.

Geology and Ground Water

Little geologic work has been done in the basin, but the well records available indicate that the surficial material in the North Branch Pawtuxet River basin is predominantly till. Most of the wells in the basin for which records are available are shallow dug wells that penetrate till and generally yield less than 5 gpm. The records indicate the till to be sandy and less than 20 feet thick in most places. In several localities bedrock crops out at the land surface. Several small outwash bodies underlying a total area of about 4 square miles are present along surface streams. The more extensive of these bodies occur along the small stream that empties into the northwest end of Scituate Reservoir and along the North Branch Pawtuxet, extending southeast from the Scituate Reservoir dam to the village of Hope (pl. 3). The first of these two bodies of outwash is narrow and probably is very thin. Thus, it is of little value for ground-water development. The most important ground-water unit in the basin is the second body of outwash, which occupies the central part of the river valley above Hope and probably extends beneath the main submerged area of Scituate Reservoir.

Ground water in the basin generally is unconfined and is replenished by the direct infiltration of water from the land surface to the water table. Because of the hilly topography and the compact character of the till in most of the basin, little of the precipitation has an opportunity to reach the zone of saturation. Much of the water either runs off over the land surface or is returned to the atmosphere by evapotranspiration. As in the other areas, the till is heterogeneous, being composed of unconsolidated material ranging in size from clay to boulders. The openings between the large-size rock fragments are filled by the small-sized material. Because the till is compact and the interstices are very small, the effective storage capacity of the till is also very small. Much of the water within the zone of saturation is held by molecular attraction and can not be recovered.

The principal body of outwash, which has an areal extent of about 1.5 square miles, is generally less than 50 feet thick. However, a number of test holes drilled in the outwash north of Hope, along the north bank of the North Branch Pawtuxet River, penetrated as much as 70 feet of outwash above the bedrock. As indicated in plate 3, the thicker part of the reservoir is areally inextensive and borders the river for only a short distance above Hope. Moreover, the logs of the test holes indicate the materials penetrated are largely fine grained. Therefore, the ability of the outwash to store and transmit water is probably small.

Estimate of Water Available

The watershed of the Scituate Reservoir occupies about 93 of the 105 square miles in the North Branch Pawtuxet River basin. Runoff and precipitation data have been collected on the watershed for the past 41 years (1915-1956) by personnel of the Water Supply Board of the city of Providence. These data are published and summarized in the annual reports of the Water Supply Board which are for each of the years ending September 30. Monthly averages of surface runoff and precipitation data for the watershed are shown comparatively in figure 2. Comparison of runoff data for the North Branch Pawtuxet River with that for other rivers indicates that it has the largest range in reported discharge of all the gaged streams in the State. This great range is largely the result of the evaporation of substantial quantities of water from the impounding reservoirs during the summer months. The least runoff on the average, occurs during the months of July and August, when air temperatures are generally highest. Runoff data indicate that, during a number of individual months of record, evapotranspiration from the watershed exceeds the runoff. The data show that on the average during the month of March the runoff exceeds the precipitation. Actually in 24 of 41 years of record, the March runoff was greater than the precipitation. Obviously in these particular years, water from melting snow, which had accumulated during the preceding winter months, produced the excess runoff.

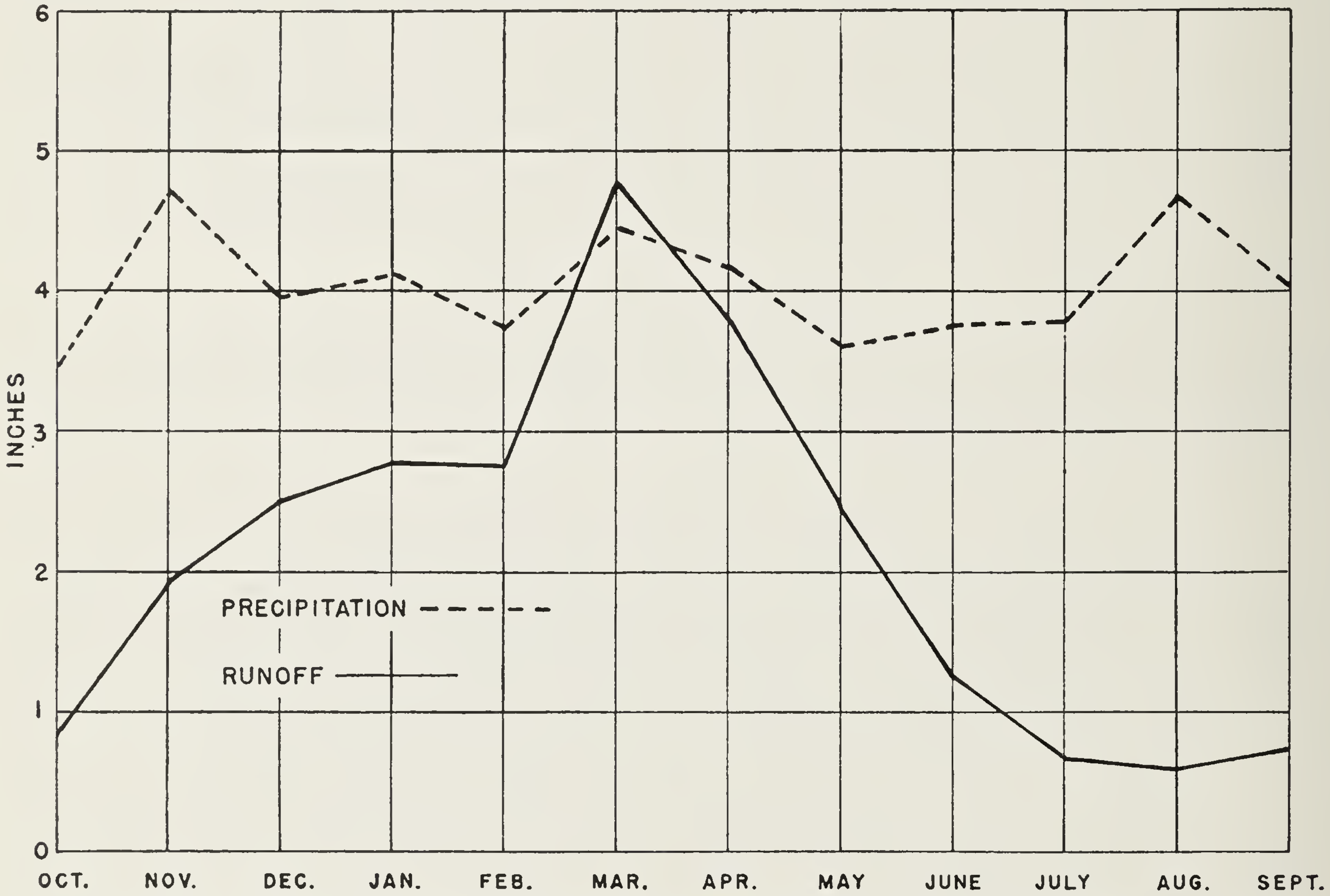

Figure 2.—Average monthly runoff and precipitation for the North Branch Pawtuxet River basin, 1916-1956.

The average annual runoff and precipitation for the period of record are about 25 and 48 inches, respectively, which indicate the evapotranspirative losses from the watershed to be about 23 inches per year. The runoff or yield of the watershed is equivalent to about 110 mgd. In 1957, the diversion of water from the Scituate Reservoir to supply the needs of the Water Supply Board customers was more than 40 mgd. The excess water is released to the river below the reservoir. It has been estimated that the safe yield (Maguire, 1952) of the Scituate Reservoir is about 85 mgd. If the use of water increases in the future as it has in the recent past, it is likely that this amount will be exceeded within the next 2 or

3 decades and the quantity of water available for release will be greatly reduced. However, sufficient water must be released from the reservoir to maintain a minimum flow in the river of 9 mgd for the needs of downstream mill interests.

The North Branch Pawtuxet River basin does not warrant quantitave study because (1) the ground-water reservoir in the basin is limited in its ability to store and transmit water and (2) large-scale development of ground water probably is not feasible.

SOUTH BRANCH PAWTUXET RIVER AREA

The South Branch Pawtuxet River area, in the central part of the State, covers about 75 square miles. The contact between the upland and lowland sections of the New England physiographic province (pl. 1) approximates a north-south line that bisects the area. The land surface in the western part, which is in the hilly upland section, range from about 400 to 600 feet altitude. In the eastern part of the area, in the lowland section, the surface generally is 200 and 400 feet altitude. The total relief is about 600 feet, as measured between Howard Hill, in the northwest corner of the area, at 680 feet altitude, and along the South Branch Pawtuxet River where it leaves the area, at about 80 feet altitude.

The total withdrawal of ground water from the South Branch Pawtuxet River area is estimated to be about 2.0 mgd. The largest user of ground water is the Kent County Water Authority, which supplies an estimated 1.4 mgd to about 28,000 persons in the towns of West Warwick, Coventry, Scituate and the city of Cranston. There is no large industrial ground-water use in the area; but a number of small diversified industries use a total of about 0.4 mgd. The remaining 0.2 mgd is used for domestic and stock purposes.

Geology and Ground Water

Approximately 50 per cent of the South Branch Pawtuxet River area is underlain by glacial outwash deposits. The outwash is concentrated in the lowland section of the eastern half of the area and in the central parts of the valleys of the streams emptying into the Flat River Reservoir (pl. 4). The outwash beneath Flat River Reservoir and Mishnock Swamp fills a preglacial bedrock channel whose position is only approximately known because bedrock data are scanty. The channel originates west of Flat River Reservoir and extends eastward beneath the reservoir and Tiogue Lake. From there it swings northward through a narrow gorge beneath the western parts of the villages of Crompton and Centerville and beneath Arctic and Riverpoint. It is filled with outwash from the Flat River Reservoir to the village of Anthony, but northeast of Anthony, the channel is filled with till. The channel may reach a maximum width of three miles between Flat River Reservoir and Tiogue Lake. The buried channel where it is filled with outwash is an important feature of the hydrology, because the lenses of permeable sand and gravel which it contains comprise the major water-bearing deposits in the area. The areal extent of the principal part of the ground-water reservoir is indicated in plate 4 by patterns showing outwash 50 to 100 and more than 100 feet thick.

A well about half a mile east of Mishnock Pond penetrated 135 feet of sediments before reaching bedrock. This is the greatest known thickness of glacial material in the area. In the Tiogue Lake area, no wells extend to bedrock, but a well drilled on the northwest shore of Tiogue Lake was finished at a depth of 92 feet in outwash. Therefore, it is not improbable that the water-bearing sediments in this vicinity are well over 100 feet thick. However, data generally are lacking as to actual thickness of the outwash in the various parts of the area, even though thicknesses greater than 100 feet are known to occur in the buried channel.

Water-table conditions generally prevail but in places where the water-bearing material is confined by lenses of fine material, the water may occur under artesian conditions. The water table is shallow, averaging about 15 feet below land surface, and is a subdued replica of the topography of the area. It is at a lower altitude and almost flat in the lowland areas adjacent to Flat River Reservoir and in Mishnock Swamp, but is at higher altitude and slopes steeply in the upland or hilly sections. The direction and velocity of ground-water movement are dependent upon the slope of the water table. Moreover, because unconfined or water-table conditions generally prevail, the many streams in the area are hydraulically connected with the ground-water body and much of the flow of the South Branch Pawtuxet River is derived from ground-water discharge.

Although the total storage capacity of the ground-water reservoir is very large, much of the usable capacity is restricted to the principal part of the reservoir in the buried valley in the eastern part of the area. Well logs indicate that in the 15 square miles of the area beneath and adjacent to Flat River Reservoir and Mishnock Swamp, the water-bearing outwash is more than 50 feet thick. The water table in this area is at or near the surface, thus it is not unreasonable to assume a 50-foot saturated thickness. Assuming a specific yield of 10 per cent, the amount of available water in storage would be 15 billion gallons. The outwash in the other parts of the area, although generally less than 50 feet thick, also contains a substantial amount of water.

Estimate of Water Available

The South Branch Pawtuxet River is gaged at the village of Washington. The drainage area of the basin above this gaging station is about 64 square miles. Discharge-duration data for the period of record 1941-1950 (Kinnison in Allen, 1953) indicate that the median daily flow of the river is about 1.5 cfs per square mile or about 62 mgd. However, the stream is largely regulated by the Flat River Reservoir which controls about 58 square miles of the gaged drainage area. It is likely that because of the regulating effects of the Flat River Reservoir the median flow of the stream is greater than it would be under natural conditions.

The Flat River Reservoir is owned and operated by the Quidneck Reservoir Co. which was formed by downstream textile interests to assure an adequate supply of water during the normal low-flow periods. The water released from the reservoir is taken from the river at the various downstream mill sites and used for cooling and process purposes, then it is returned directly to the stream. Very little water is actually consumed in the various industrial processes. However, about 0.5 mgd is diverted from Carr Pond in the southern part of the basin by the Kent County Water Authority in addition to the 1.4 mgd of water that it obtains from the ground-water reservoir. Part of the water pumped by the Water Authority is used in the area, so the amount of water consumed or diverted from the area, is small.

The creation of a surface reservoir has been proposed for the Big River in the southern part of the area. The dam would be constructed between two till-bedrock hills near the entrance to the southern arm of the Flat River Reservoir (Maguire, 1952). The proposed reservoir which would have a spillway altitude of 300 feet would flood an area of about five square miles and have a drainage area of about 30 square miles. The construction of such a reservoir would drastically reduce the effective contributory area and the safe yield of the Flat River Reservoir. It would also inundate part of the area underlain by thick and permeable outwash material although, a substantial part of the outwash tract in the Mishnock River sub-basin and in the Washington-Tiogue Lake area would still be available for development.

The safe yield (Maguire, 1952) of the proposed Big River reservoir is estimated to be about 38 mgd. Taking into account the current (1957) usage, consumption and diversion of water in the basin, and the median flow of the stream, about 20 mgd remains available. Because of the substantial amount of water available and the large extent and thickness of permeable outwash, the South Branch Pawtuxet River area is suitable for quantitative study.

POTOWOMUT-WICKFORD AREA

The Potowomut-Wickford area is in the central part of the State bordering Narragansett Bay (pl. 1). It has an extent of about 59 square miles which includes the basins of the Potowomut and Annaquatucket Rivers.

The topography consists largely of broad, rolling hills that increase in altitude to the west. Except in the extreme western part of the basin, surface altitudes are less than 300 feet and local relief is generally less than 100 feet. The total relief is about 450 feet, as measured between the highest point along the southwestern topographic divide at an altitude of about 450 feet, and the shoreline along the bay at sea level.

The Potowomut River, which is called the Hunt River in its upper reaches, heads in the west-central part of the area and flows northeastward to Greenwich Bay. The northwestern part of the area is drained by a number of small streams that originate near the western divide and flow eastward to join the Potowomut in the central part of the area. The Annaquatucket River heads in the southwest and flows east to Narragansett Bay. The extreme southern part of the area is drained by south-flowing tributaries of the Pettaquamscutt River. (See pl. 4.)

The largest user of ground water in the area is the U. S. Navy, which pumps an average of about 2 mgd from two large-diameter wells near the Hunt River in the central part of the area. The Kent County Water Authority also has two large-diameter wells near the Hunt River upstream from the Navy wells. About 1.25 mgd are withdrawn from these wells. The Authority supplies water to parts of the towns of East Greenwich and North Kingstown and the city of Warwick. The North Kingstown Water Commission has two wells in the Belleville Pond area from which about 0.5 mgd is presently (1957) being withdrawn. The industrial and domestic use of ground water in the area is small, probably in the order of 0.25 mgd. Therefore, the estimated total usage of ground water in the Potowamut-Wickford area is about 4.0 mgd.

Geology and Ground Water

More than 50 per cent of the Potowomut-Wickford area is underlain by glacial outwash deposits. The deposits underlie almost the entire eastern half of the area, and in the northwest occur in the valleys of Mawney and Frenchtown Brooks (pl. 4).

The outwash in the eastern part of the area has a total extent of about 32 square miles. However, it is interrupted in a number of places by bodies of mixed glacial deposits (outwash and till) and till-bedrock hills so that the net areal extent of the outwash is about 25 square miles. Well logs indicate that the outwash varies greatly in thickness, and in several parts of the area, outwash fills and conceals preglacial bedrock channels. The extent and thickness of the principal outwash body in the area are shown in plate 4 by the patterns indicating outwash thicknesses of 50 to 100 and 100 or more feet. The thickest deposit is in the buried channel in the Potowomut River valley where the bedrock lies more than 100 feet below the land surface. Several other deep places in the bedrock surface which may or not be in preglacial bedrock channels are indicated. The most notable of these are in the valley of the west tributary of the Pettaquamscutt River and beneath and west of Belleville Pond.

The outwash in the northwestern part of the area fills a shallow tributary bedrock channel that originates at the northern boundary of the area and extends south and east beneath Mawney Brook to a point east of Frenchtown. The channel then trends east as a narrow gorge for about half a mile, but widens before joining the main channel underlying the Potowomut River. Though the outwash filling the tributary channel extends into the South Branch Pawtuxet River area to the north, a bedrock high is present beneath the boundary which serves as a ground-water barrier. Much of the tributary channel is filled with outwash, generally less than 50 feet thick, and is from ½ to ¾ of a mile wide, but the narrow gorge east of Frenchtown is filled with till.

Water-table conditions prevail in much of the area, but artesian conditions are encountered in the southwest at the base of the morainal hill in the headwaters of the Annaquatucket River. Silt and clay are sufficiently thick to confine water in the shallow underlying stratum of sand and gravel. The depth to water is generally less than 10 to 15 feet. The storage capacity of the materials in the basin is relatively large, but much of the effective capacity is limited to the outwash in the principal part of the ground-water reservoir in the eastern part of the area, especially in the buried channel beneath the Potowomut River. The central part of the Potowomut valley, in which the outwash is more than 50 feet thick, is about half a mile wide and about 4 miles long. Assuming a specific yield of 10 per cent and considering only the uppermost 50 feet of saturated thickness, the amount of available water stored in this part of the ground-water reservoir is about 2 billion gallons.

Most of the wells tapping the ground-water reservoir in the area supply water for domestic and stock purposes. The withdrawals from these wells are usually less than 25 gpm, but these generally reflect the capacities of the pumps and not the ability of the aquifer to yield water to the wells. The only large capacity wells in the part of the reservoir in the Potowomut valley are the four owned by the Kent County Water Authority and the U. S. Navy near the Hunt River about 1.6 miles southwest of East Greenwich. Each of these wells was initially tested at a rate exceeding 1,000 gpm. The maximum recorded well yield in the area, and in the entire State, is 2,700 gpm from one of the Water Authority wells. In the Belleville Pond area, the two wells of the North Kingstown Water Commission were also initially tested at rates exceeding 1,000 gpm.

Estimate of Water Available

Substantially more ground water than was used in 1957 is available for development in the Potowomut-Wickford area. In addition to the large volume of water in storage, much water that is presently being discharged from the area could be made available for future use if the resources were properly developed.

An estimate of the amount of water available in the area is possible from an evaluation of stream runoff and precipitation data. The Potowomut River is gaged about 2½ miles upstream from the mouth of the river. Because the geology of the basins of the various streams in the area is alike the records for the Potowomut River are considered to be representative of the discharge characteristics of the other streams in the area. Thus, an evaluation of hydrologic data for the Potowomut River is applicable to the entire Potowomut-Wickford area.

The discharge of the Potowomut River, which has a drainage area of 23 square miles above the gaging station near East Greenwich, has been measured since September 1940. The data are presented in a series of U. S. Geological Survey water supply papers entitled "Surface Water Supply of the United States, Part 1A, North Atlantic Slope Basins, Maine to Connecticut" and in the annual reports of the Rhode Island Department of Public Works. The average monthly runoff, in inches, and the average

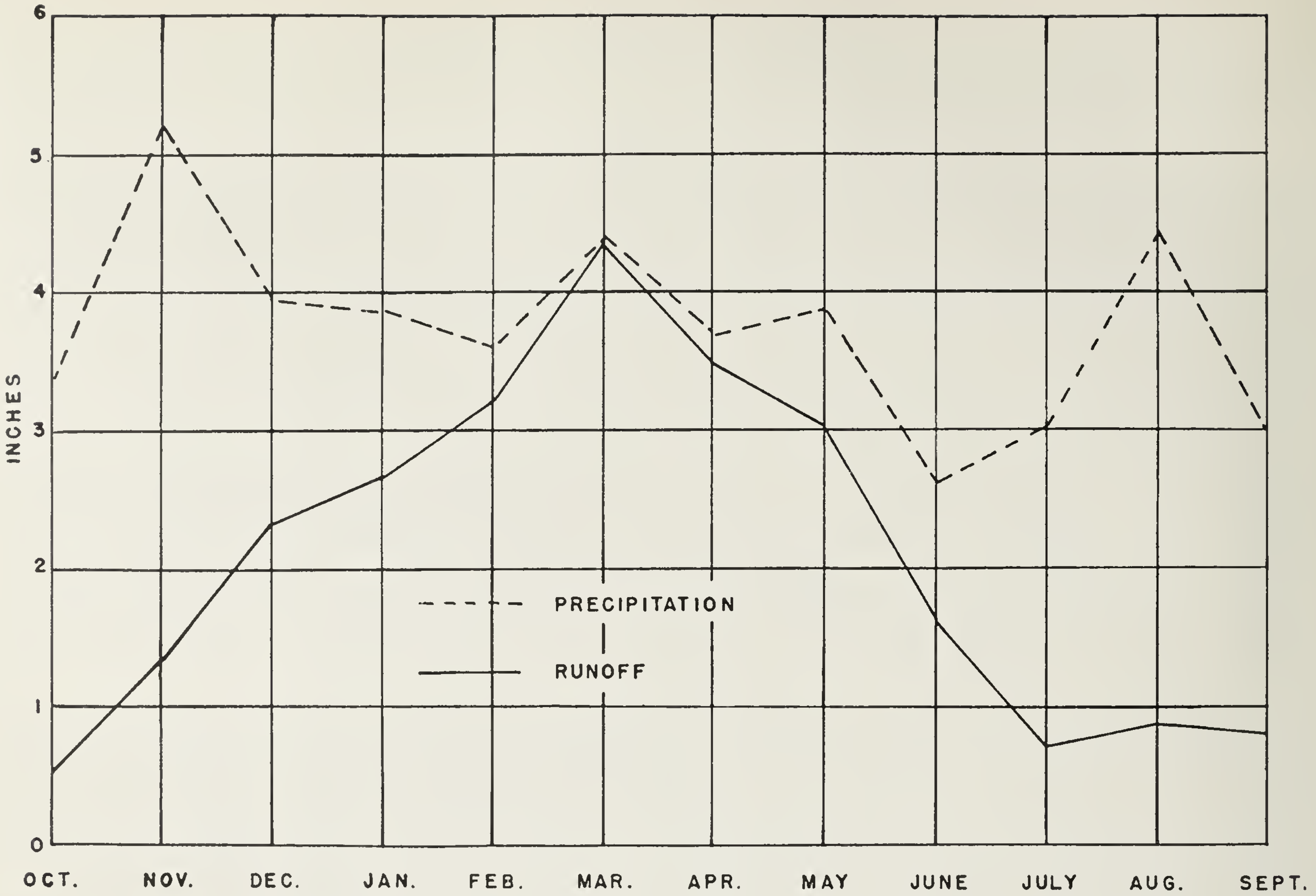

Figure 3.—Average monthly runoff, 1941-1955, and precipitation, 1940-1956, for the Potowomut River basin.

monthly precipitation are plotted in figure 3 for water-years through 1955. Although the period of record for the runoff data is slightly shorter than for the precipitation data, the average figures would be little changed if the same period of record were used for both.

Whereas the flow of the streams in the other areas previously studied is regulated by reservoirs and mills, the flow of the Potowomut River is unregulated. Although the streamflow is affected to a small degree by pumpage, a comparison of runoff and precipitation data (fig. 3) gives a general picture of the hydrology of the basin. Streamflow is greatest during the winter and early spring months. The reasons for this may be: (1) during this period the ground-water reservoir is generally full, thus recharge is rejected making more water available for direct runoff to the streams; (2) evapotranspiration is at a minimum; (3) when the ground-water reservoir is full, the hydraulic gradient from the aquifer to the stream is steepest and maximum ground-water discharge takes place; and (4) during the winter some water may be stored on the ground as ice and snow. In the spring the ice and snow melt and either sink into the ground or run off.

During the growing season, which extends from about the first of May to about the middle of October, evapotranspiration is high. Consequently little of the rain that falls during this period reaches the stream or recharges the ground-water reservoir. During the latter part of the year, stream discharge increases because of a reduction in evapotranspiration, which makes a larger part of the precipitation available for direct runoff and ground-water recharge. As the ground-water reservoir fills, a corresponding increase in ground-water discharge takes place concurrently with the steepening of the hydraulic gradient toward the stream.

Although a substantial part of the streamflow consists of ground-water discharge, it is difficult to determine exactly what part of the runoff is ground water without a detailed evaluation of the many hydrologic factors that are effective within the basin. However, an estimate of ground-water discharge may be obtained by assuming that all streamflow during the latter part of the growing season is derived from ground-water discharge, and that ground water discharges at the same rate during the other months of the year. Any determination of ground-water discharge thus obtained is a minimum, because, as previously mentioned, the discharge varies with the hydraulic gradient toward the streams. This gradient is generally greatest in March or April and least in September or October. The use of low-water runoff data that includes several storms does not obviate the validity of such an estimate because the value computed is then closer to the true value for ground-water discharge than if only dry-weather runoff data were used in the determination. The discharge data shown in figure 3 are computed from observed streamflow and therefore reflect the diversions of water that are made above the gaging station from wells of the U. S. Navy and Kent County Water Authority. This diverted water is mostly used outside the Potowomut basin, and thus is lost to the basin. Because the ground-water reservoir is hydraulically connected with the river, the streamflow is reduced by an amount essentially equivalent to that pumped from the wells. The effects of the diversions are more pronounced during the summer months, when the streamflow is a minimum and the usage of water is greater than at any other time of the year. The use of the runoff data for the low flow months as shown in figure 3 would result in a low estimate of the annual ground-water recharge and discharge.

The average daily withdrawal of water from the Navy and Water Authority wells during the summer months is in the order of 4 mgd. This is about 0.13 inches of water per month for the entire Potowomut River basin. This amount added to the average observed monthly runoff for the summer months gives an adjusted average monthly ground-water discharge of 0.87 inches. Using the adjusted figure, the average annual recharge to and discharge from the ground-water reservoir in the Potowomut River basin is at least 10 inches of water. The observed average yearly runoff from the basin is about 25 inches per year. Assuming that this figure and the figure of 10 inches for ground-water discharge are applicable to the entire Potowomut-Wickford area, then the surface discharge is about 25,600 million gallons or, on an average daily basis about 70 mgd of which at least 28 mgd is ground water.

Because there are only two surface-water developments in the area, which use a total of about 0.4 mgd, there seems little likelihood of conflict between ground-water and surface-water uses. As evidenced by available well logs and reported well yields, the outwash in the area is thick and extensive and also highly permeable. Because substantial quantities of water are available for development, the Potowomut-Wickford area is considered suitable for quantitative investigations.

UPPER PAWCATUCK RIVER BASIN

The upper Pawcatuck River basin is an irregularly-shaped basin in the south-central part of Rhode Island (pl. 1). Its drainage area comprises about 70 square miles upstream from a point about half a mile east of the village of Kenyon in the southwest corner of the basin.

The northern half of the basin consists largely of broad, rolling hills interrupted by numerous narrow, south-trending valleys. The southern half is essentially a flat plain, at altitudes of 90 and 100 feet, locally interrupted by small hills which stand as much as 140 feet above the surrounding general level. The total relief in the basin is about 510 feet, as measured between the highest point, Pine Hill, on the western boundary at 550 feet altitude, and the lowest point, the Pawcatuck River at Kenyon, at about 40 feet altitude.

Ground-water usage in the upper Pawcatuck River basin is about 2 mgd. The largest user of ground water in the basin is the Wakefield Water Co., which pumps about 0.8 mgd from three gravel-packed wells in the extreme southeastern part of the basin. An average of about 0.4 mgd is used at the University of Rhode Island, which obtains its supply from two gravel-packed wells near Thirty Acre Pond in the central part of the basin. The Bernon-Lemoine Water Co., which supplies part of the town of South Kingstown obtains about 0.3 mgd from a spring near the village of Kingston. The Ladd School, which is in the north-central part of the basin, uses about 0.15 mgd. About 0.35 mgd is used for domestic and stock purposes.

Geology and Ground Water

An estimated 45 per cent of the upper Pawcatuck River basin is underlain by outwash deposits. In the northern part of the basin, the outwash only partly fills the stream valleys. It is limited to the central parts of the valleys and to the vicinity of the present-day streams. In the southern part of the basin, the outwash is much more extensive—completely filling and concealing preglacial bedrock valleys (pl. 5).

The outwash-filled bedrock channel in the valley of the Usquepaug (Queen) River originates near the northwestern boundary of the basin. It trends southeast beneath Fishersville Brook to Bear Swamp, west of Ladd School, thence southwest beneath the Queen River to Usquepaug. It then passes south and southeast beneath the Great Swamp to Wordens Pond, where it is joined by a short tributary channel from the Chipuxet River valley. From Wordens Pond, the channel trends southeast beneath the Charlestown moraine which forms the southern boundary of the basin. The channel continues to Block Island Sound.

The most extensive body of outwash is in the southern part of the basin, where it conceals the bedrock channels. The outwash body extends south from a line through the village of Usquepaug, Barber Pond, and Hundred Acre Pond to the foot of the Charlestown moraine and includes the Great Swamp, north and northwest of Wordens Pond. However, it is interrupted at several places by isolated till-bedrock hills which stand 40 to 140 feet above the general level of the surrounding outwash.

The full thickness of the outwash in many parts of the basin is not known. In the north, where the deposits are not widespread the outwash is probably less than 50 feet thick. The outwash in the buried channels thickens to the south as the bedrock in the channels slopes more steeply than does the land surface. This is indicated by data from wells in the Usquepaug-Queen River and Chipuxet River valleys. In the Usquepaug-Queen River valley, a well drilled at the Ladd School encountered bedrock at a depth of 96 feet, whereas a well about 1½ miles northeast of Usquepaug and about 3¼ miles southeast of Ladd School penetrated 122 feet of outwash without reaching bedrock. In the Chipuxet River valley, a well adjacent to Thirty Acre Pond, about 1¼ miles northwest of Kingston, was drilled 132 feet to bedrock, whereas north of Larkin Pond, about 1¼ miles south of the well at Thirty Acre Pond, a well 165 feet deep did not encounter bedrock. In both valleys, the northern wells are at higher altitude than the southern wells. From this evidence it appears that the outwash in the southern part of the basin is relatively thick. Actually, the extensive outwash tracts in the basin constitute one large water-bearing unit, the outwash filled Usquepaug-Queen River and Chipuxet River valleys forming arms of the main body of the unit in the Great Swamp-Wordens Pond area.

There is no evidence that the ground water in the basin is under artesian conditions. The water table is generally within 10 feet of the land surface, and in the Great Swamp area the water table is at or near the surface. Because the water table is near the land surface in much of the basin where the outwash is relatively thick, the zone of saturation is therefore relatively thick and contains a very large volume of water. Assuming a specific yield of 10 per cent, each square mile of saturated outwash contains about 20 million gallons of available ground water per foot of thickness. It is estimated that the saturated outwash is more than 50 feet thick in about 20 square miles of the basin. Therefore, a minimum estimate of the amount of available water in storage is 20 billion gallons. The actual volume of water stored is undoubtedly much greater, because, as previously indicated, the outwash in parts of the basin is well over 100 feet thick and the areal extent of the permeable glacial material is much greater than 20 square miles.

The wells owned by the University of Rhode Island, the Wakefield Water Co., and the Ladd School indicate the sizable well yields that may be expected from properly constructed wells tapping the permeable outwash. One of the university wells had a tested yield of more than 900 gpm, although it is now pumped at a much reduced rate. The Wakefield Water Co., whose well field is in the southeastern corner of the basin, has three production wells, the initial yields of which ranged from 560 to 800 gpm. Two wells owned by the Ladd School had tested yields of 260 and 350 gpm.

Estimate of Water Available

The upper Pawcatuck River basin is part of the Pawcatuck River drainage area, the runoff from which is measured at the stream gaging station at Wood River Junction. The total drainage area above the gaging station is about 100 square miles of which the upper basin comprises 70 square miles. Streamflow records indicate that the average yearly runoff from the total area is about 24 inches. A detailed analysis of streamflow hydrographs, made for a report covering part of the upper Pawcatuck basin, showed the ground-water discharge to be about 17 inches per year (Bierschenk, 1957) which is equivalent to about 0.8 mgd per square mile. From this, the average recharge to and discharge from the ground-water body in the upper Pawcatuck basin is estimated to be about 56 mgd.

Discharge-duration data presented by Kinnison (in Allen, 1953) indicate that the median discharge from the upper basin is about 1.3 cfs per square mile or about 59 mgd. The close agreement between the ground-water discharge and the median flow emphasizes the effectiveness of the ground-water reservoir in storing and subsequently releasing water to the surface streams.

Except for one small development which entails less than 0.1 mgd, the surface-water resources of the basin are undeveloped. Moreover, the basin is topographically unsuitable for the construction of surface reservoirs. Because of the substantial amounts of ground water available and the comparatively large size and effective area of the ground-water reservoir, the upper Pawcatuck River basin warrants detailed quantitative study.

WOOD-PAWCATUCK AREA

The Wood-Pawcatuck area, in the southwestern part of the State (pl. 1), has an areal extent of about 123 square miles. The area consists largely of broad, rolling hills aligned in a general north-south direction. The higher hills and greatest surface altitudes are in the northwestern corner; however, the highest point in the area, at about 560 feet altitude, is Escoheag Hill, which is about 0.75 mile from the State border and 0.75 mile north of the Exeter-West Greenwich town line (pl. 5). The lowest point in the area is at the boundary in the southwest where the Pawcatuck River leaves the area, at about 40 feet altitude. The surface in much of the area is generally between 100 and 400 feet altitude.

The population of the Wood-Pawcatuck area is about 5,000; mostly in the villages of Hope Valley, Wyoming, Alton, Carolina, Wood River Junction, Shannock, Kenyon, and Arcadia, which are in the south and central parts of the area. Ground-water use is estimated to be in the order of 1.0 mgd. The largest user of ground water is the Sun Chemical Co. plant, which is located at Wood River Junction, and pumps about 0.6 mgd from a gravel-packed well near the Pawcatuck River. The only public supply in the area is owned by the Richmond Lace Works which furnishes water to a company housing development in Alton. The company, which serves about 0.05 mgd to about 200 persons, obtains its supply from a shallow dug well near the Wood River. The remaining 0.35 mgd are used in several small industries and for domestic and stock purposes.

Geology and Ground Water

About 35 per cent of the Wood-Pawcatuck area is underlain by glacial outwash deposits. Much of the outwash is confined to the central part of the Wood River valley and to the valleys of several other tributaries of the Pawcatuck River. The outwash fills bedrock channels that underlie the Wood River, Beaver River, and White Brook (pl. 5).

The most extensive body of outwash is in the bedrock channel of the ancestral Wood River. The channel extends south from the junction of Phillips Brook and Acid Factory Brook beneath Hope Valley to about half a mile north of Alton. From there it trends southeast beneath School House Pond to Block Island Sound. A tributary channel from the White Brook valley extends south for some distance beneath the Pawcatuck River and then joints the Wood River channel south of Wood River Junction. In the Beaver River valley in the eastern part of the area, the outwash-filled channel originates south of Ten Rod Road and extends south beneath the confluence of the Beaver and Pawcatuck Rivers. It continues south beneath Pasquiset Pond and beyond the area boundary. The locations of the buried channels are approximately indicated in plate 5 by the extent of outwash that is greater than 50 feet thick.

In the intervalley part of the area south of Woodville and Carolina, outwash generally less than 50 feet thick occurs as a broad plain that is interrupted locally by isolated till-bedrock hills. Relatively thin outwash deposits also are present in the short, narrow valleys of the tributaries of the Wood River. In the Phillips Brook and Acid Factory Brook valleys, outwash extends upstream from the confluence of the streams for about 1 and 1½ miles, respectively. The outwash body in the valley of the Falls River extends southeast to join the main body south of the West Greenwich-Exeter town line. Outwash also fills the valleys of the streams northwest of Hope Valley and Woodville.

Most of the wells in the basin are shallow dug or driven wells and do not reach bedrock. Therefore, detailed data are lacking as to (1) the configuration of the bedrock surface, (2) the exact positions of the central parts of the buried channels, and (3) the full thicknesses of valley-fill deposits. However, well logs indicate a southward slope of the bedrock surface beneath the Wood River valley of about 18 feet per mile. Thus, the altitude of the bedrock surface beneath the junction of the Phillips and Acid Factory Brooks is estimated to be about 140 feet higher than beneath Hope Valley. From this it is likely that wells drilled along a particular surface contour within the valley would penetrate a greater thickness of outwash in the southern part of the valley than in the northern part.

As in the other areas of the State, the character of the outwash material varies greatly, not only areally but with depth at the same location. The grains of material or rock fragments vary in size from silt to coarse gravel and the beds in which they occur vary greatly in thickness and generally lens out in relatively short distances.

Ground water in the basin is generally unconfined; however, because of lithologic differences mentioned above, artesian or confined conditions may be encountered locally. The water table in the outwash is at or near the land surface in the swamps and adjacent to the surface streams, but is as much as 15 feet below the land surface inland from the Pawcatuck River and its tributaries. The storage capacity of the outwash aquifers is large, but sufficient data are not available on which to base an estimate of the gross storage capacity of the outwash in the entire area. The capacity of the outwash to store water is demonstrated by estimating the volume of water stored in the part of the reservoir formed by the elongate outwash body in the Wood River valley north of Hope Valley. This body has an area of about 10 square miles. Assuming a specific yield of 10 per cent, each foot of saturated material would contain about 200 million gallons of available water. The actual thickness of the material in the outwash body is not known, but in only the uppermost 50 feet of saturated thickness, the amount of available water stored would be about 10 billion gallons.

Estimate of Water Available

Precipitation and streamflow records indicate that a large volume of water enters and passes through the area each year. In addition to the water that is derived directly from precipitation within the area, a median flow of 59 mgd enters the area via the Pawcatuck River from the upper Pawcatuck River basin. However, as the water resources of the upper Pawcatuck River basin are developed, less water may be available for release to the downstream areas.

The drainage from about 72 square miles (includes 11 square miles in Connecticut) is measured at a gaging station on the Wood River at Hope Valley. Available discharge-duration data (Kinnison in Allen, 1953) indicate that the median discharge of the stream is about 1.4 cfs per square mile or about 65 mgd. A comparison of discharge data for all the gaged streams in the State shows that the median discharge per square mile of drainage area of the Wood River above Hope Valley is, with one exception, greater than that for any other stream. This is the result of greater precipitation than elsewhere in the State (48 inches annually) and the presence of the extensive tract of saturated outwash in the central part of the stream valley. The outwash is capable of absorbing and storing large quantities of water during the non-growing season, which is subsequently released to the stream. The runoff from a total of about 100 square miles is measured. According to streamflow data, the median surface discharge per square mile for the entire area is about 1.3 cfs which is equivalent to about 110 mgd (total drainage area is 134 square miles including 11 square miles in Connecticut).

The surface-water usage in the area is about 1.5 mgd. However, little of this water is actually consumed and none is diverted from the area. Thus, the available water resources, both surface and ground, remain essentially undiminished by the present-day development. The saturated outwash is thick and extensive and is capable of sustaining large capacity wells as evidenced by the 500 gpm installation of the Sun Chemical Co. at Wood River Junction. The Wood-Pawcatuck area warrants quantitative groundwater study.

LOWER PAWCATUCK RIVER AREA

The lower Pawcatuck River area in Rhode Island has an areal extent of about 47 square miles in the extreme southwestern corner of the State (pl. 1). The area is in the Seaboard Lowland section of the New England physiographic province. The topography consists of gently rolling hills, the summits of which are generally at altitudes between 200 and 300 feet, but whose bases are generally less than 200 feet. The total relief is about 417 feet, as measured between Champlin Hill, in the northwestern part of the area, and the Pawcatuck River at the village of Westerly at mean sea level.

The quantity of ground water used in the area is about 2.0 mgd. The largest user of ground water is the Westerly Water Department, which supplies a large part of the town of Westerly and the village of Pawcatuck, Conn. The department pumps about 1.8 mgd from 3 well fields. The White Rock and Varietyville well fields are about 1.5 and 2 miles, respectively, north of Westerly on the east bank of the Pawcatuck River, and the Bradford well field is about 1 mile south of the village of Bradford and about 4.5 miles northeast of Westerly. Another public supply in the basin, owned by the Bradford Dyeing Association, supplies water to a company housing development in the village of Bradford. The Bradford Co. serves an estimated 400 persons and obtains its supply from a field of 7 wells on the north bank of the Pawcatuck River.

Geology and Ground Water

It is estimated that about 50 per cent of the lower Pawcatuck River area is underlain by outwash deposits. The extent of the outwash in the area is shown in plate 5. However, much geologic work remains to be done in the area, especially in the town of Westerly, where the extent and thickness of the outwash are only approximately known. The most extensive tracts of outwash are in the central part of the area along the Pawcatuck River and in the south extending from the Westerly-Bradford Road to the foot of the Charlestown moraine, near and parallel to the Post Road.

The outwash deposits in the area are all interconnected, so that for all practical purposes, one extensive outwash aquifer is present in the area. The areal extent of the aquifer needs to be more accurately determined, as do the thickness and permeability of the materials comprising the aquifer. In the western part of the area north of the village of Westerly the outwash tract is rather narrow, being limited to the central part of the Pawcatuck valley. Well logs for the White Rock and Varietyville well fields of the Westerly Water Dept. indicate that the saturated outwash in this part of the area is moderately thick. A number of test holes at the well fields penetrated as much as 90 feet of unconsolidated material without striking bedrock. The water department has 166 wells of 2½-inch diameter which range is depth from 35 to 80 feet and have a total yield of about 2,600 gpm. The yield of any one particular well is small; however, because the wells are closely spaced, the aggregate yield indicates that the outwash in the ground-water reservoir is relatively permeable. In addition, a large-diameter, gravel-packed well constructed at the White Rock station in 1953 had a capacity of more than 700 gpm. This indicates the magnitude of yield that may be expected from a well tapping the permeable outwash.

East of Potter Hill, the outwash tract extends north into the Ashaway River valley and south to the Charlestown moraine. However, the areal extent of the outwash is interrupted by till-bedrock hills, the largest of which are near the Westerly-Charlestown town line (pl. 5). Few records of the thickness of the outwash in this part of the area are available. In the village of Ashaway, a well penetrated 79 feet of unconsolidated material before striking bedrock. At Bradford, 7 wells of the Bradford Dyeing Assoc. ranging in depth from 60 to 67 feet did not encounter bedrock. Similarly, 25 wells of the Westerly Water Dept. at its Bradford station about 1 mile south of Bradford were drilled to depths ranging from 35 to 55 feet without reaching bedrock. Of course, the outwash is thin in the vicinity of the till-bedrock hills. Data are also lacking as to the true ability of the permeable outwash material in this part of the area to yield water to wells. The Dyeing Assoc. and Water Dept. wells had initial total capacities of 150 and 250 gpm, respectively, however, these wells are 2½-inch diameter drive-pipes. The other wells tapping the reservoir in this part of the area are mostly shallow dug or driven wells that yield 5 to 10 gpm.

Ground water in the outwash is generally unconfined, although artesian conditions may exist locally. In much of the area, the water table is within 10 feet of the land surface; the water table is at or near the surface in the vicinity of the Pawcatuck River and in the swampy tract south of Chapman Pond. Because few records of the thickness of outwash are available, the gross storage capacity of the material cannot be estimated. However, assuming a specific yield of 10 per cent, each square mile of outwash would contain about 20 million gallons of available water per foot of saturated material. The magnitude of the effective storage capacity is indicated by the areal extent of the outwash, which is more than 20 square miles, and its thickness, which is more than 90 feet in places.

Estimate of Water Available

The discharge from the lower Pawcatuck River area is measured at the gaging station on the Pawcatuck River in the village of Westerly in the southwest corner of the area. Actually, the discharge measured is from the entire Pawcatuck River basin which has a drainage area of about 295 square miles. In addition to the water derived directly from precipitation, runoff from the Wood-Pawcatuck area and the upper Pawcatuck River basin passes through the lower Pawcatuck area and is measured at Westerly.

Discharge-duration data for the Pawcatuck River basin (Kinnison in Allen, 1953) indicate that the median discharge of the stream is equivalent to about 1.3 cfs per square mile of drainage area. Therefore, the median discharge of the lower Pawcatuck River area is about 61 cfs or 39 mgd. The combined drainage areas of the Wood-Pawcatuck area and the upper Pawcatuck River basin is more than 200 square miles. Thus, the median inflow to the lower area from the upstream drainage areas is about 170 mgd. However, if the water resources of the upper areas are developed in the future, the inflow to the lower area may be greatly reduced.

The surface-water use in the lower area is about 8 mgd, largely by the Bradford Dyeing Assoc. The association takes water directly from the river above the plant and returns it at a down-stream point; consequently, the use is essentially non-consumptive. The lower Pawcatuck River area is considered suitable for quantitative study because of the extensive and relatively thick permeable outwash deposits in the area and the substantial quantities of water available.

SOUTH COASTAL AREA

The South Coastal area borders Block Island Sound and southwest Narragansett Bay (pl. 1) and has an areal extent of about 75 square miles. The northeastern part of the area is drained by the Pettaquamscutt and Saugatucket Rivers. The southern part of the area paralleling the sound is drained by a number of short, narrow streams that flow south from an east-west ridge (Charlestown moraine) which forms the north boundary, into the tidal ponds. The ponds are protected by barrier beaches along the sound.

The greatest surface relief is in the Pettaquamscutt Valley in the northeast part of the area where it is about 150 feet. The relief in the south is generally 50 to 100 feet as measured between the summits of the hills on the ridge at altitudes of 100 to 150 feet and the base of the ridge at about 50 feet. Because the land along Block Island Sound and Narragansett Bay is at sea level, the maximum relief is the same as the altitude of the highest point in the area. This point is Tefft Hill on the northwest boundary at about 260 feet altitude.

The South Coastal area is largely developed for recreational purposes because of the many fine beaches along Block Island Sound and Narragansett Bay. The year round population of the area is estimated to be about 10,000; however, the summer population is many times larger. Almost the entire population of the area is served by the Wakefield Water Co. which has a ground-water source in the upper Pawcatuck River basin. There are two small ground-water supplies in the area, one at the Charlestown Naval Air Station which, in 1957 served only a small maintenance force. The other serves a small summer housing development in the northeast. There is no industrial development in the area and the domestic use of ground water is small. The total ground-water withdrawal in the South Coastal area is estimated to be about 0.1 mgd.

Geology and Ground Water

About 25 square miles of the land part of the area is underlain by outwash deposits (pl. 1). As indicated the outwash is more or less confined to the Pettaquamscutt and Saugatuck River valleys in the northeast and to the lowland part of the area extending south from the foot of the Charlestown moraine (the longitudinal ridge) to Block Island Sound.

The thicker outwash deposits occur in several preglacial bedrock channels which extend south beneath the sound. A channel west of Point Judith Pond is the continuation of the main channel in the Wordens Pond area of the upper Pawcatuck River basin. Farther west, the bedrock channels of the ancestral Wood and Beaver Rivers of the Wood-Pawcatuck area join near the village of Charlestown and continue southeast beneath the sound. The very narrow, moderately deep channel of the ancestral Pettaquamscutt River and the shallow channel in the Saugatucket valley are tributaries of the channel west of Point Judith Pond.

The outwash-filled channels generally constitute the principal parts of the ground-water reservoir in the area. However, in the South Coastal area, with the exception of the channel in the Saugatucket valley and a short stretch of the channel in the Pettaquamscutt valley, the buried channels either pass beneath or lie adjacent to tidal ponds or streams. The deposits in these channels are largely filled with salty water. Thus, the principal parts of the ground-water reservoir in the South Coastal area from which fresh ground water may be obtained are (1) the outwash tracts in the south situated between the tidal ponds and the foot of the Charlestown moraine, (2) the tracts in the northeast in the shallow bedrock channel of the Saugatucket valley, and (3) the stretch of about 1 mile northeast of Point Judith Pond in the Pettaquamscutt valley.

Well logs indicate that the outwash in the south and in the Saugatucket valley is generally less than 50 feet thick and contains water under water-table conditions. The water table is generally within 10 feet of the land surface. However, the stretch of bedrock channel of the ancestral Pettaquamscutt River northeast of Point Judith Pond underlies a present-day stream valley where the outwash in the channel is at places more than 50 feet thick and contains water under artesian conditions. A number of test holes drilled in the stream valley indicate that the outwash is capped by a shallow stratum of peat and clay which is extensive in the central part of the valley. Many of the test wells in the valley flowed; apparently, the artesian aquifer is recharged principally by water that moves laterally from the sides of the valley.

Little information is available indicating the ability of the permeable outwash to transmit and yield substantial quantities of water to individual wells. The largest yield from a well in the area was from a test well constructed in the artesian aquifer northeast of Point Judith Pond for the town of Narragansett during a search for a town water supply. This well was pumped for a prolonged period at the rate of 250 gpm.

Estimate of Water Available

The parts of the ground-water reservoir suitable for development in the Pettaquamscutt River valley and in the south adjacent to the tidal ponds have small areal extent. Withdrawals of ground water from the aquifers near the tidal-water bodies would result in the encroachment of salt or brackish water and the contamination of parts of the reservoir. Therefore, the development of the ground-water reservoir must be remote from the saltwater bodies and the quantity of water available for development is limited to the ground-water recharge from local precipitation. Because of the extensive shorelines of the tidal ponds and streams, and barrier beaches, only relatively small sections of the ground-water reservoir in these parts of the area are suitable for development; and because of the thin zone of saturation, large capacity wells probably are not feasible.

The artesian aquifer northeast of Point Judith Pond is replenished by water that moves beneath the confining stratum from the sides of the narrow valley. The average annual precipitation is about 42 inches which is equivalent to about 2 mgd per square mile. However, it is estimated that only about half of the precipitation recharges the aquifer. As the surficial area of the valley is only about 0.5 square mile, the quantity of water available for development from the artesian aquifer probably does not exceed 0.5 mgd.

The largest stream in the South Coastal area containing fresh water is the Saugatucket River which has a drainage area of about 7 square miles. As mentioned on page 30 the permeable outwash in the Saugatucket basin is generally much less than 50 feet thick; however, its thicker sections are in the lower reaches of the stream. Therefore, the more suitable sites for the development of sizable ground-water supplies in the Wakefield area are in the lower part of the Saugatucket basin and near the stream. The average annual runoff of the Saugatucket River based on the diagram by Knox and Nordenson (1955) showing the average annual runoff in the New England states is about 24 inches. On an average daily basis, this is equivalent to about 8 mgd. However, the amount of water perennially available for development would be less than 8 mgd because of the limited areal extent and thickness of the outwash deposits and the direct dependence of any ground-water development on the availability of recharge from the Saugatucket River. Discharge-duration data for other streams in the southern part of the State (Kinnison in Allen, 1953) indicate that the median stream discharge is about 1.3 cfs per square mile. Assuming the median discharge of the Saugatucket River is of the same magnitude, this would total about 6 mgd. The discharge data also show that the stream discharge for a large part of the time is less than 0.8 cfs per square mile, which, for the Saugatucket, would be less than 4 mgd.

The amount of water available for development in the South Coastal area is relatively small as is the areal extent of the sections of the ground-water reservoir suitable for development. Therefore, the South Coastal area does not warrant quantitative study.

EASTERN BAY AREA

The Eastern Bay area, as the name implies, includes the part of the State along the east shore of Narragansett Bay. It also includes the islands in the bay. Specifically, the area is comprised of the southern part of the town of Bristol; the towns of Tiverton, Little Compton, Jamestown, Portsmouth, and Middletown; and the city of Newport. It has a total land area of about 120 square miles.

The mainland part of the area consists of gently rolling hills; it is drained by numerous short, narrow streams that flow south and east. The largest of these streams is Adamsville Brook which has a drainage area of about 9 square miles in the southeastern part of the area. Altitudes are everywhere less than 300 feet and generally less than 200 feet.

The population of the area is estimated to be about 73,000 of which about 38,000 is in the city of Newport. There are several public water supplies in the area. The largest is the municipal supply of Newport which obtains about 6 mgd from surface reservoirs within the city, in Lawtons Valley in the town of Portsmouth, and in the town of Middletown. Several small public supplies in the towns of Portsmouth and Tiverton use ground water. These supplies furnish a total of about 0.2 mgd. An additional 0.1 mgd of ground water is used by several diversified industries in Portsmouth and Newport. The largest use of ground water in the area is for domestic and stock purposes which is estimated to be about 1.5 mgd. Therefore, the total ground-water usage is estimated to be in the order of 1.8 mgd.

Geology and Ground Water

Only about 4 of the 120 square miles in the Eastern Bay area are underlain by outwash deposits. The remainder of the area is underlain by till, through which bedrock protrudes in several localities. As indicated in plate 1, shallow inextensive deposits of outwash are present in the towns of Bristol, Tiverton, and Portsmouth. Because of the scarcity of geologic data, the thickness and character of the outwash are not well known. The few available well logs indicate that the outwash is generally less than 20 feet thick.

Almost all of the wells in the area are shallow dug wells which obtain water from till. Reported well yields vary, but are generally less than 5 gpm. The yields of several wells are insufficient even for domestic purposes. The water table is replenished by the direct percolation of water from the land surface to the zone of saturation. However, because of its clayey character, the material generally has a very low infiltration capacity. Consequently, very little of the precipitation that falls actually reaches the zone of saturation. In addition, most of the water within the zone of saturation in the till is held by molecular attraction. Consequently, the specific yield is very low and little water is available for recovery through wells. Most of the precipitation that falls is disposed of by evapotranspiration and direct runoff.

During the winter and early spring months, the flow of the streams in the area responds rapidly to precipitation because evapotranspiration is at a minimum and the infiltration capacity of the soil is quickly exceeded even during storms of low intensity and fairly short duration. During the summer and early fall months, evapotranspiration accounts for much of the rainfall and the flow of the streams consists almost entirely of ground-water discharge. However, because of the small storage capacity of the aquifers in the basin, very little water is available for release to the streams.

Estimate of Water Available

Few hydrologic data are available on which to base an estimate of available water in the area. The only stream for which runoff records are available is the Adamsville Brook. Surface runoff and precipitation data for the basin of Adamsville Brook are presented in figure 4. The correlation between runoff and precipitation is more direct for the Adamsville Brook basin than for any other gaged stream in the State. This is more or less indicated by the sizable increase in average runoff for August in response to the greater average precipitation which is the result of several hurricanes which occurred during the month.

The average runoff of Adamsville Brook during the months of July, August, September, and October is about 0.45 inch. Assuming that much of this runoff is ground-water discharge and is therefore representative of the magnitude of ground-water discharge in the other months of the year, then about 5.5 inches of the average yearly runoff from the basin is ground water. This figure also represents the amount of ground-water recharge.

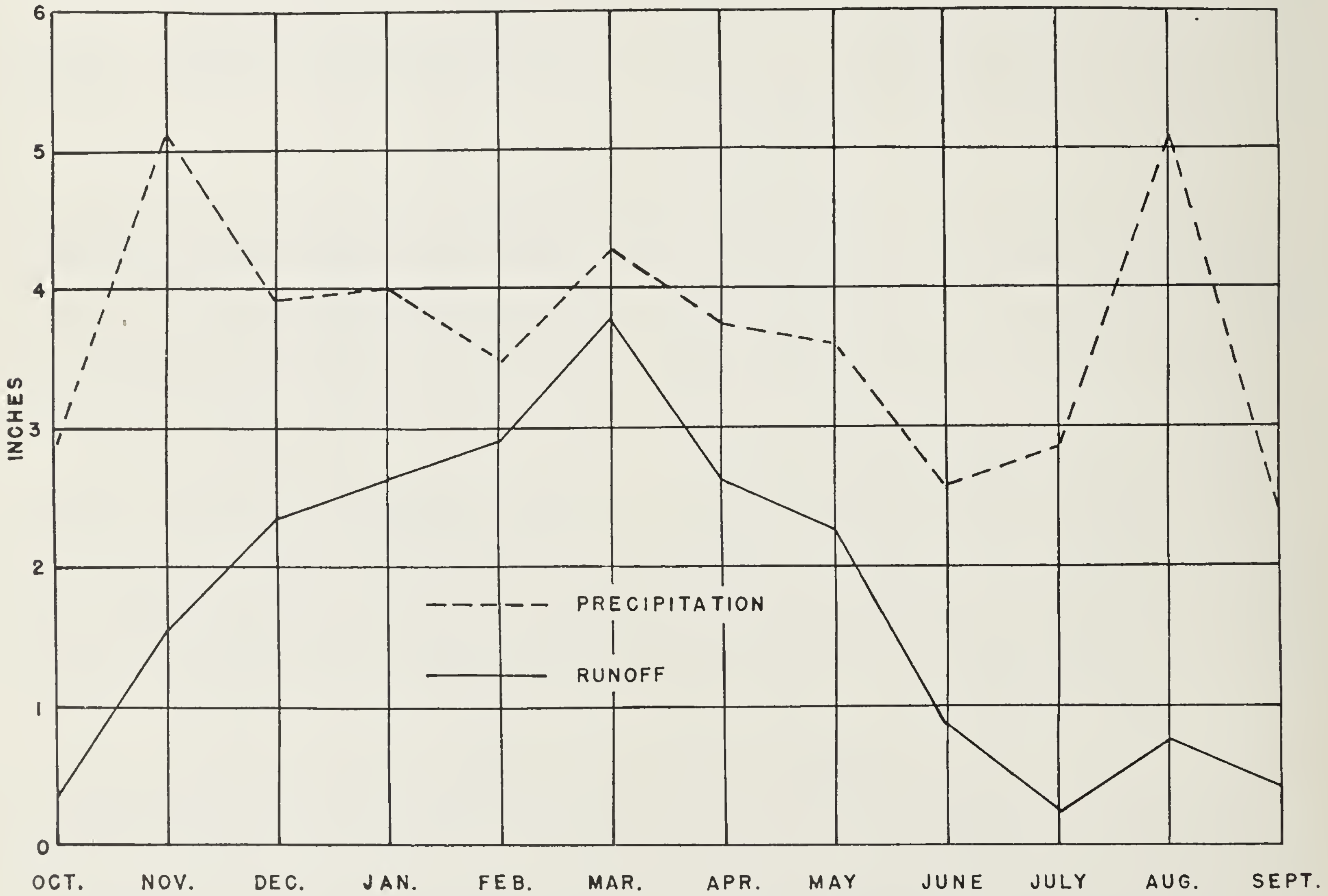

Figure 4.—Average monthly runoff, 1941-1955, and precipitation, 1940-1956, for the Adamsville Brook basin.

The average annual precipitation in the Adamsville Brook basin is about 43 inches. The average yearly runoff from the basin is about 21 inches, thus evapotranspiration is about 22 inches. Because one inch of water on the drainage area is equivalent to about 156 million gallons, the total amount of water available yearly from all sources, as indicated by the surface runoff, is about 3,275 million gallons. On an average daily basis, this is equivalent to about 9 mgd, of which about 2.5 mgd is ground water Applying these data to the entire Eastern Bay area it is apparent that additional quantities of water are available for development. However, because of the low specific yield of the till deposits, much of this water is available only to low-yield wells. Of the areas studied, the Eastern Bay area is the least favorable for the development of ground-water supplies for industrial or municipal purposes. Therefore, this area is not suitable for quantitative investigations.

BLOCK ISLAND

Block Island, the town of New Shoreham, is about 12 miles south of the mainland in the Atlantic Ocean, between latitudes 41°08′35″ and 41°13′55″ N and longitudes 71°32′40″ and 71°36′50″ W. The island, which is roughly triangular, has an area of about 11 square miles, about 2 square miles of which are water. The base of the triangle, along the southern shore, is about 3.5 miles, and the altitude, the distance from the south shore to the northern tip of the island, is about 6 miles.

The several ponds in the central part of the island are interconnected and divide the island into two sections, which are joined by a narrow strip of land along the east shore. The northern section, which is referred to locally as "the Neck'" is fairly flat and surface altitudes are generally less than 50 feet, but the land surface rises gradually northeastward to about 100 feet at the sea cliff of the east shore. The southern section of the island is more hilly. Altitudes increase southward to the sea cliff of the south shore which is at about 140 feet. The total relief of the island is about 180 feet. Altitudes range from sea level along the shores to about 211 feet on the summit of Beacon Hill in the western part of the island. The island has no well-defined streams; surface drainage collects in a number of small depression ponds, which drain underground to the surrounding ocean.

The Block Island Water Co. furnishes the only public supply on the island. It serves about 150 of the all-season population of about 750 and about 3,000 summer residents. The company has a combined surface- and ground-water supply at Sands Pond, but wells are used only to meet peak demands. Water consumption ranges from about 7,500 gpd during the winter season to more than 100,000 gpd during the summer season. The majority of the island population is dependent upon privately owned wells for its water supply. The average daily withdrawal of ground water on Block Island is estimated to be about 15,000 gpd.

Geology and Ground Water

The island is underlain by thick deposits of unconsolidated materials, some of which are of glacial origin. However, no detailed geologic field studies of the island have been made and data are lacking as to the thickness, and areal extent of till and outwash deposits.

Of the 46 wells for which information was available, 1 was dug, 9 were driven, and 36 were drilled. The dug and driven wells range in depth from 10 to 37 feet, and the drilled wells range from 32 to 244 feet. Reported information as to the position of the bedrock surface and thickness of unconsolidated materials is available from only one of the drilled wells. This well was drilled north of Sands Pond for the Block Island Water Co. It was reported by the driller that 195 feet of unconsolidated material was penetrated before encountering bedrock. The altitude of the land surface at the well site is about 130 feet; hence, if the report is accurate, the altitude of the bedrock surface is about 65 feet below mean sea level. The deepest well for which data are available was drilled in the north-central part of the island. It was 244 feet deep and did not encounter bedrock. Therefore, at this well site the altitude of the bedrock is more than 170 feet below mean sea level. In addition, the nautical chart of the Block Island area, published by the U. S. Coast and Geodetic Survey, indicates that parts of the ocean bottom surrounding the island are at a lower altitude than the bedrock surface in the water company well. This implies that a bedrock high may be present at the southeastern end of the island and that the bedrock surface may slope downward in all directions from this point. Because no additional bedrock data are available, the slope of the bedrock surface cannot be determined.

Well logs and outcrops show that the unconsolidated materials consist of bodies of till, stratified sand and gravel, and clay. Beds of coarse sand and gravel, which may be excellent sources of ground water where tapped by properly constructed large diameter wells, are present. However, the depths and thicknesses of these beds are generally unpredictable and they may not be extensive. A number of wells drilled in the southwestern and southeastern parts of the island penetrated 54 to 140 feet of till and (or) clay. Wells drilled in the south-central part of the island penetrated 138 to 157 feet of alternating strata of till and (or) clay and coarse sand and gravel.

Ground water on the island occurs locally under artesian conditions. These conditions are produced by shallow bodies of till and clay, which occur at various depths on the island. The bodies are not sufficiently permeable to permit water to percolate readily downward to beds of coarse material which lie at greater depths. Water-level data indicate that wells tapping permeable material at shallow depths have higher water levels than wells tapping deeper permeable material. This is clearly shown in the three wells of the Block Island Water Co., which are alined north of Sands Pond. The two northern wells are screened in gravel at about 130 feet depth and have water levels about 50 feet below the land surface. The well closest to the pond is finished in a gravel stratum at 80 feet depth and has a water level only about 25 feet below the surface. In addition, the water level in Sands Pond is about 20 feet above that in the closest well, indicating that the pond and the water body tapped by the shallower well are perched. However, because of a lack of detailed water-level data, it is not known whether other ponds and swamps on the island are perched also.

Of the 36 drilled wells for which records are available, 3 are owned by the Block Island Water Co. and 1 is owned by the Block Island Airport, the remainder are privately owned wells used for domestic supplies. Eleven of the 32 wells drilled for domestic supplies did not yield sufficient quantities of water even for domestic purposes, and the remainder have reported yields ranging from 5 to 25 gpm. The more successful wells are those used for public supplies, which yield 35 to 60 gpm. Almost all of the wells were drilled to obtain relatively small quantities of water and, therefore, may not test the ability of the aquifers to yield water. A detailed study of the ground-water resources of the island is necessary to determine more accurately the capabilities of the aquifers to store and transmit water.

Estimate of Water Available

On Block Island, except during the most severe storms, water from precipitation is either returned to the atmosphere by evapotranspiration or infiltrates into the ground to recharge the ground-water body.

The average annual precipitation on the island is about 39 inches. Assuming that evapotranspirative losses are of the same magnitude as in drainage basins in the southern part of the State, about 17 inches is available for recharging the ground-water reservoir. On a land area of about 9 square miles, 1 inch of water is equivalent to about 156 million gallons. Therefore, a total of about 2,650 million gallons or about 7 mgd is estimated to be perennially available. The present use of water on Block Island is relatively small and, it is not expected that the need for water will increase substantially in the foreseeable future. Hence, a quantitative study of the ground-water resources of the island is not considered necessary.

AREAS SUGGESTED FOR FURTHER STUDY

Of the 17 ground-water reservoir areas appraised, 8 warrant quantitative studies to determine the magnitude of their available ground-water supplies. The areas were selected for some or all of the following reasons: (1) they contain extensive tracts of highly permeable outwash; (2) substantial quantities of water are available for replenishment; (3) their ground-water resources are essentially undeveloped; and (4) ground-water developments will not conflict with established surface-water uses. The eight areas are listed below in a suggested order for study. The order is based on the indicated industrial expansion and population growth in the State with their accompanying water-supply demands, and the areas in which they are likely to occur. However, it is not unlikely that the order in which the areas are eventually studied will differ from that presented here owing to changes in the need for water and the need for quantitative ground-water information. The suggested order of study is as follows:

(1) Upper Pawcatuck River Basin
(2) Blackstone River Area
(3) Pawtucket-East Providence Area
(4) Providence-Warwick Area
(5) Potowomut-Wickford Area
(6) South Branch Pawtuxet River Area
(7) Wood-Pawcatuck Area
(8) Lower Pawcatuck River Area

Field studies have largely been completed and reports or maps are in preparation or already published on the ground-water resources of some topographic quadangles comprising the areas listed above. These reports and maps are based on inventories of well and boring data and geologic field studies of rock outcrops and glacial deposits. Because existing data in these areas are generally incomplete and insufficient, much additional data would be needed to determine accurately the extent and thickness of the outwash aquifers and the hydraulic characteristics of the materials of which they are composed. More hydraulic data are also required to understand more fully the hydrology of the areas in order that refined estimates of the magnitude of their available ground-water supplies can be made.

To satisfy the indicated data requirements, a quantitative program as envisaged for each study area would entail the following: (1) seismic exploration to determine the extent and thickness of the ground-water reservoirs, (2) test drilling to ascertain the physical character of the materials comprising the reservoirs, (3) observation-well networks to evaluate the seasonal changes in volume of water stored in the reservoirs, (4) aquifer-performance tests to evaluate the abilities of the reservoirs to transmit, store, and subsequently release water to wells, (5) precipitation and evaporation measurements to indicate the areal distribution and amount of water falling on the study areas and the part of the precipitation that returns directly to the atmosphere, (6) streamflow measurements to determine the quantity of water entering and (or) leaving the study areas in the streams, and (7) chemical analyses of water samples to indicate the usefulness of the water for various purposes. Because the suggested study areas differ greatly in size, the scope of the quantitative program for each study area must be determined separately as must the cost of studying each area.

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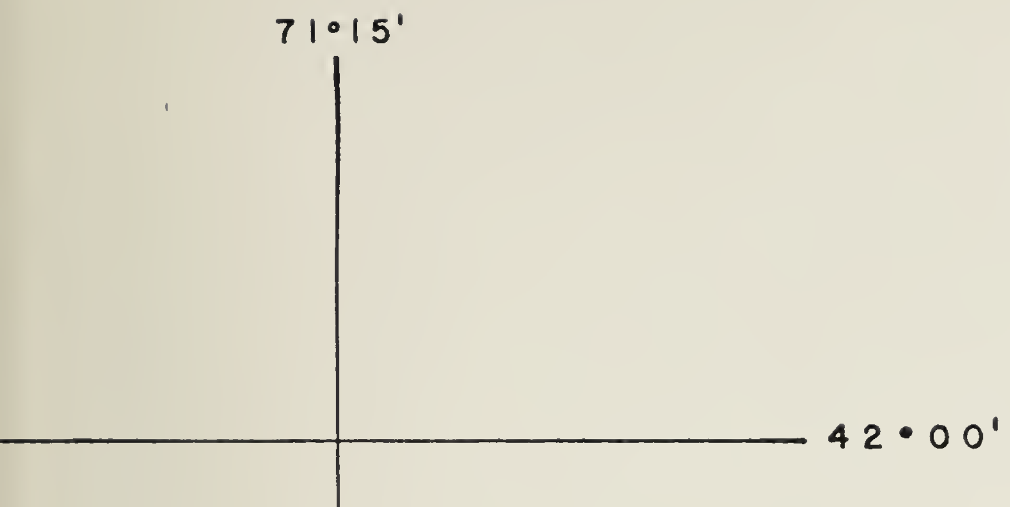

GROUND-WATER STUDY AREAS

1. UPPER BRANCH RIVER AREA
2. NORTH SMITHFIELD-WOONSOCKET AREA
3. BLACKSTONE RIVER AREA
4. UPPER WOONASQUATUCKET RIVER AREA
5. PROVIDENCE-WARWICK AREA
6. PAWTUCKET-EAST PROVIDENCE AREA
7. BARRINGTON-WARREN AREA
8. QUINEBAUG RIVER AREA
9. NORTH BRANCH PAWTUXET RIVER BASIN
10. SOUTH BRANCH PAWTUXET RIVER AREA
11. POTOWOMUT-WICKFORD AREA
12. UPPER PAWCATUCK RIVER BASIN
13. WOOD-PAWCATUCK AREA
14. LOWER PAWCATUCK RIVER AREA
15. SOUTH COASTAL AREA
16. EASTERN BAY AREA
17. BLOCK ISLAND

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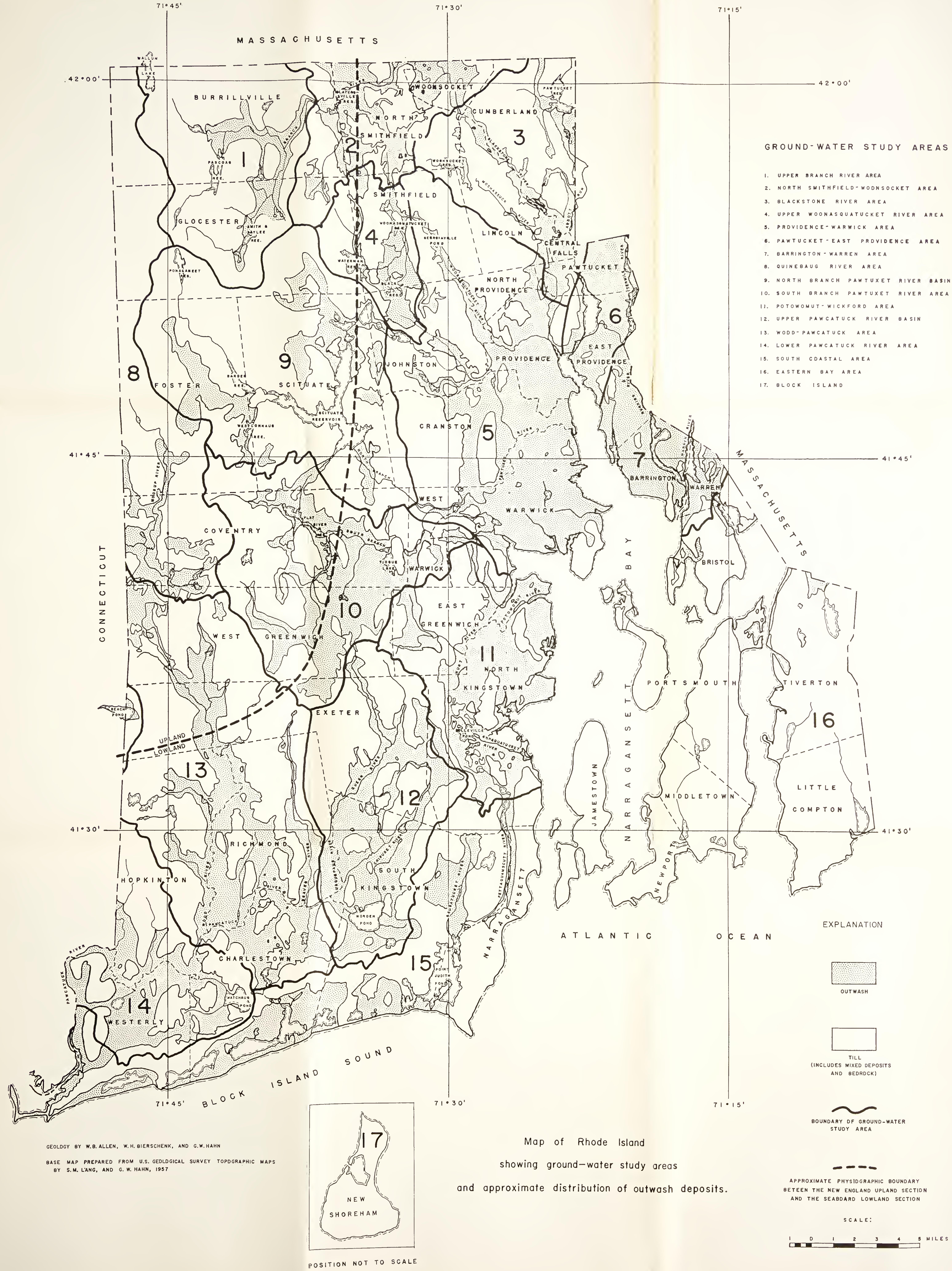


GROUND-WATER STUDY AREAS

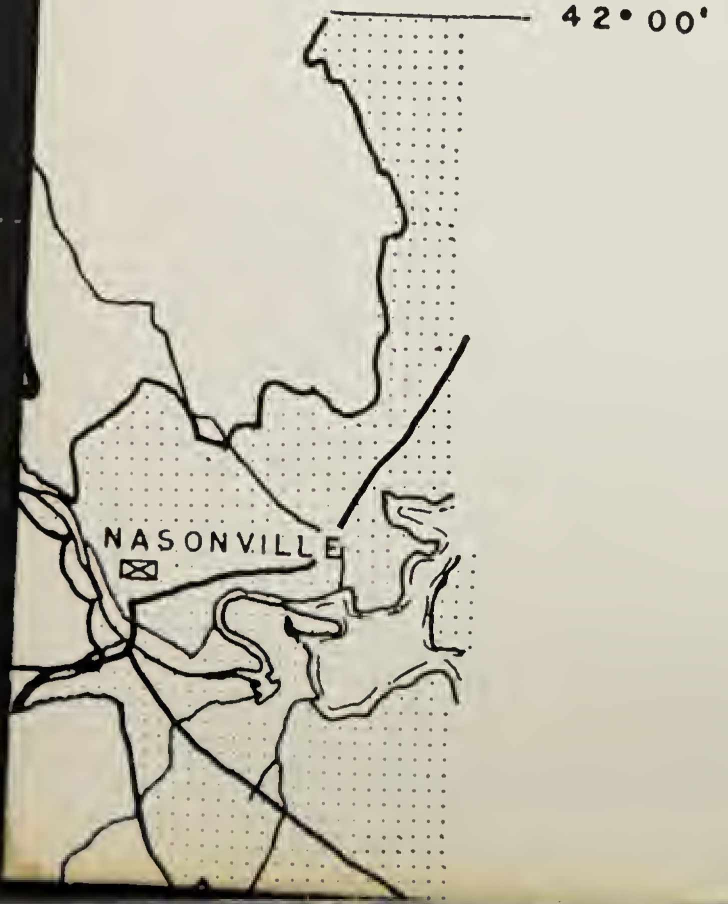
1. UPPER BRANCH RIVER AREA
2. NORTH SMITHFIELD-WOONSOCKET AREA
3. BLACKSTONE RIVER AREA
4. UPPER WOONASQUATUCKET RIVER AREA
5. PROVIDENCE-WARWICK AREA
6. PAWTUCKET-EAST PROVIDENCE AREA
7. BARRINGTON-WARREN AREA
8. QUINEBAUG RIVER AREA
9. NORTH BRANCH PAWTUXET RIVER BASIN
10. SOUTH BRANCH PAWTUXET RIVER AREA
11. POTOWOMUT-WICKFORD AREA
12. UPPER PAWCATUCK RIVER BASIN
13. WOOD-PAWCATUCK AREA
14. LOWER PAWCATUCK RIVER AREA
15. SOUTH COASTAL AREA
16. EASTERN BAY AREA
17. BLOCK ISLAND

Map of Rhode Island
showing ground-water study areas
and approximate distribution of outwash deposits.

GEOLOGY BY W.B. ALLEN, W.H. BIERSCHENK, AND G.W. HAHN

BASE MAP PREPARED FROM U.S. GEOLOGICAL SURVEY TOPOGRAPHIC MAPS
BY S.M. LANG, AND G. W. HAHN, 1957

PLATE 2

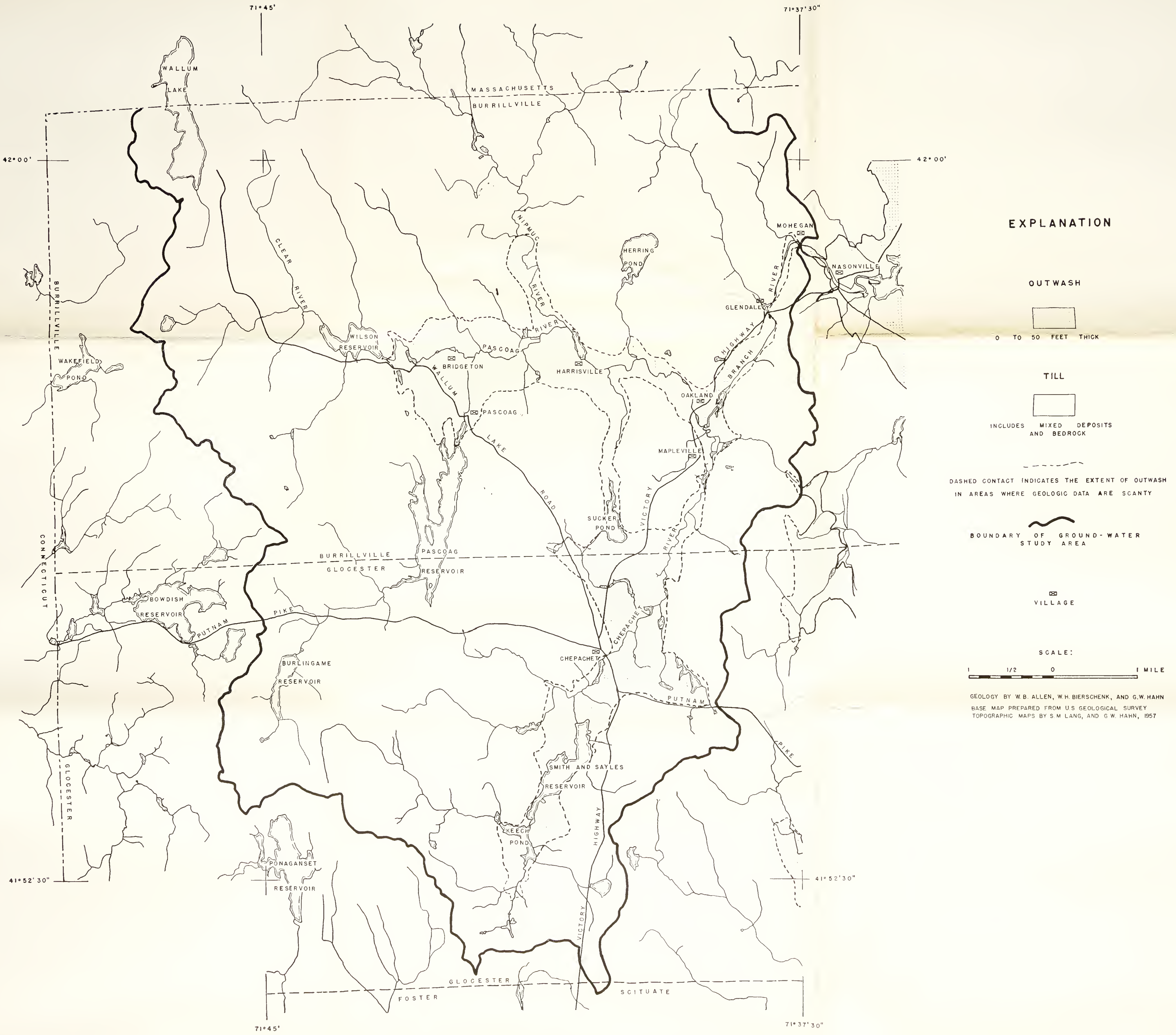


EXPLANATION

OUTWASH

▨

557
R346g
no. 11



GEOLOGY BY W.B. ALLEN, W.H. BIERSCHENK, AND G.W. HAHN
BASE MAP PREPARED FROM U.S. GEOLOGICAL SURVEY TOPOGRAPHIC MAPS BY S.M. LANG, AND G.W. HAHN, 1957

Map of Rhode Island part of upper Branch River Area showing extent and thickness of outwash deposits.

PLATE 3

EXPLANATION

OUTWASH

░

0 TO 50 FEET THICK

▤

50 TO 100 FEET THICK

▥

100 OR MORE FEET THICK

TILL

□

INCLUDES MIXED DEPOSITS
AND BEDROCK

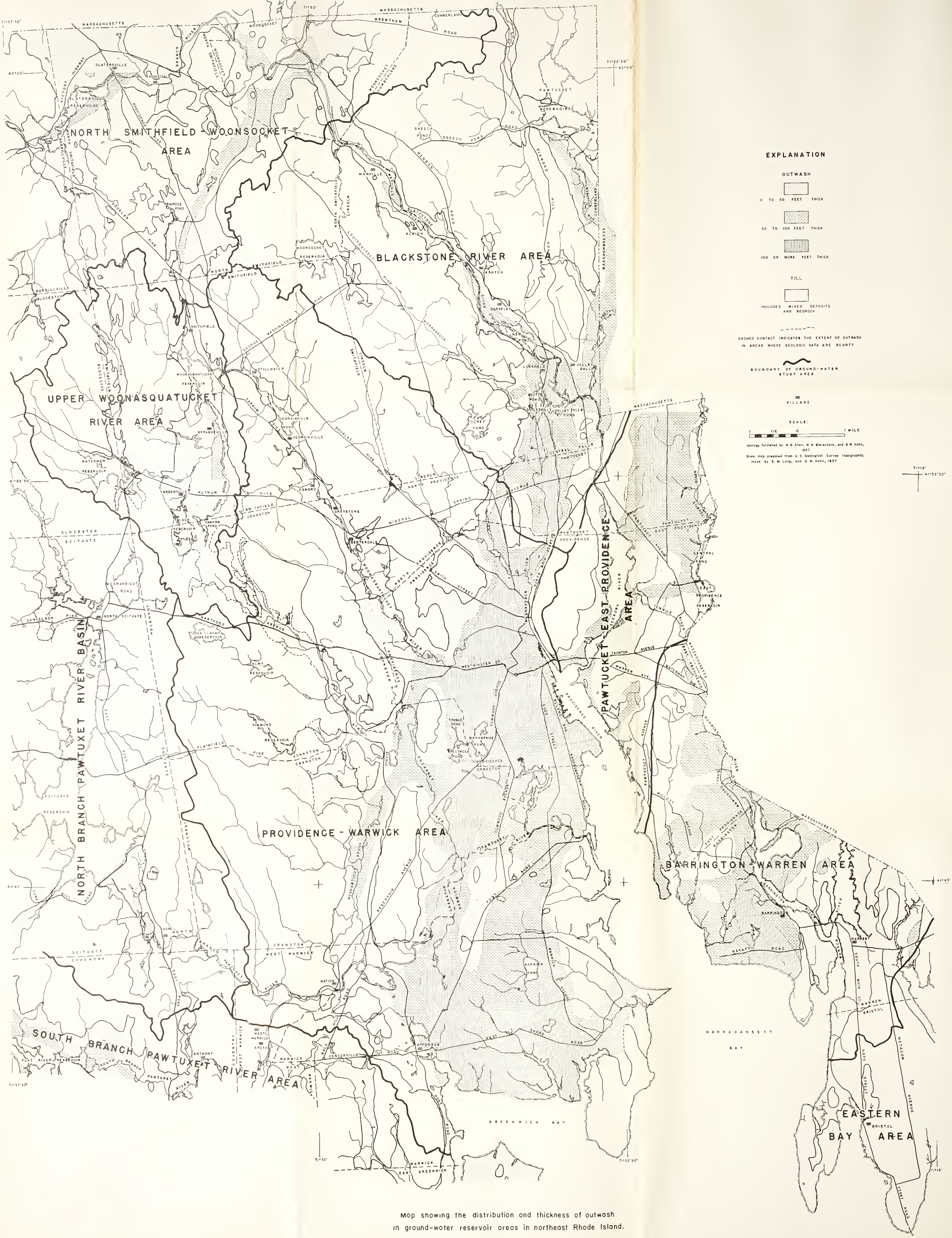
- - - - - -

DASHED CONTACT INDICATES THE EXTENT OF OUTWASH
IN AREAS WHERE GEOLOGIC DATA ARE SCANTY

〰

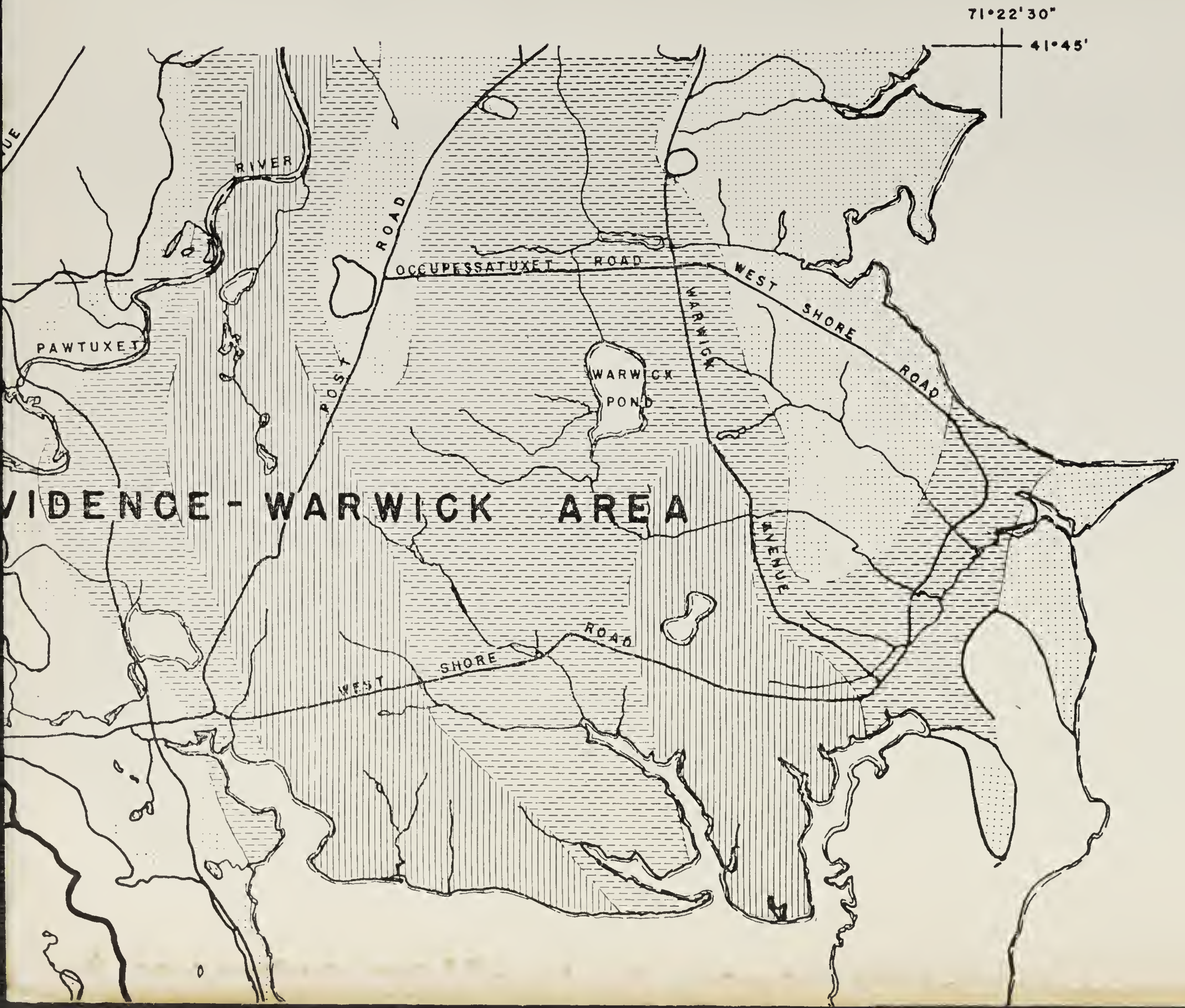
BOUNDARY OF GROUND-WATER
STUDY AREA

557
R346g
no. 11

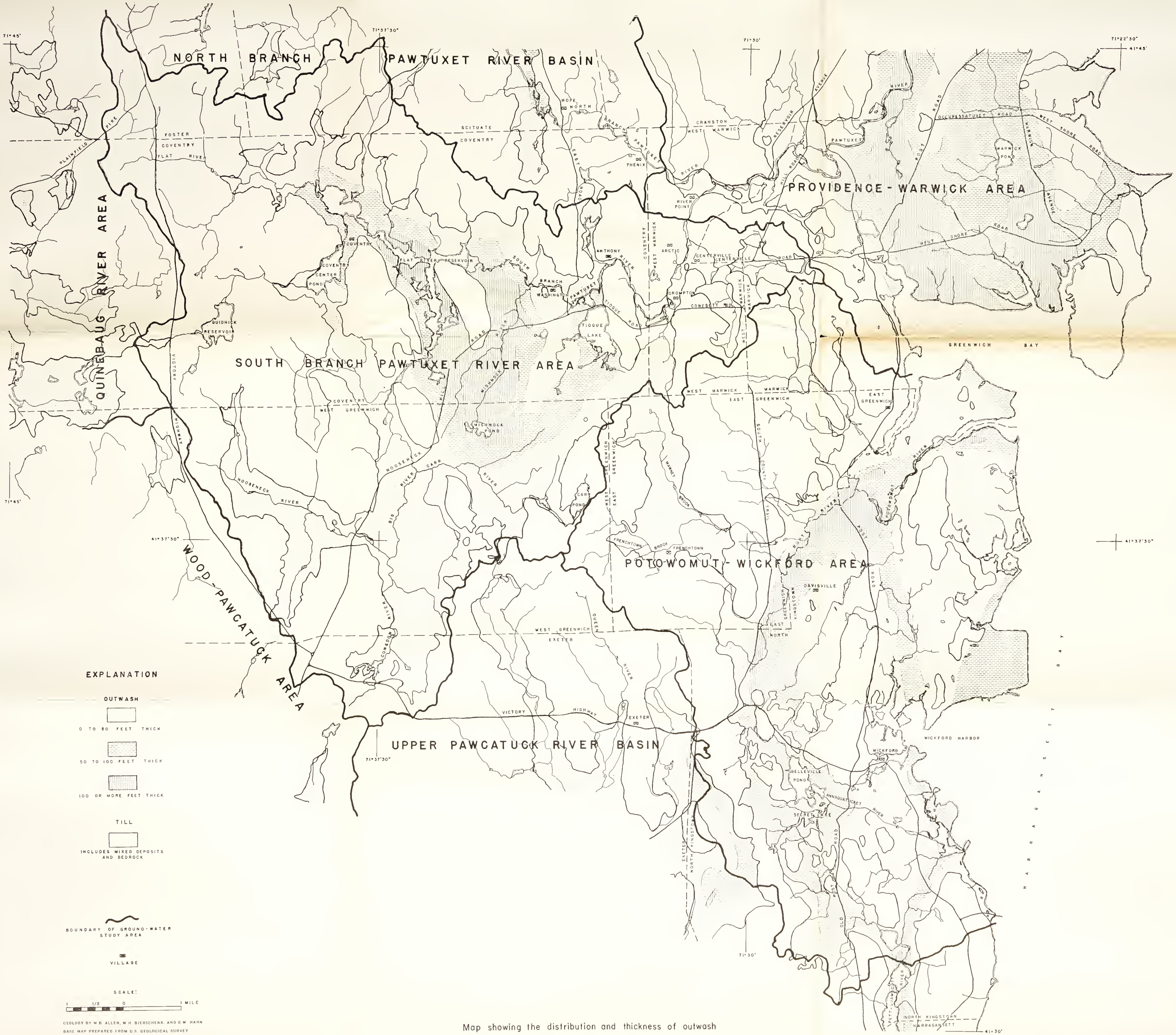

NORTH SMITHFIELD-WOONSOCKET AREA
BLACKSTONE RIVER AREA
UPPER WOONASQUATUCKET RIVER AREA
NORTH BRANCH PAWTUXET RIVER BASIN
PROVIDENCE-WARWICK AREA
PAWTUCKET-EAST PROVIDENCE AREA
BARRINGTON-WARREN AREA
EASTERN BAY AREA
SOUTH BRANCH PAWTUXET RIVER AREA
MASSACHUSETTS
NARRAGANSETT BAY
GREENWICH BAY
71°37'30"
71°30'
71°22'30"
71°15'
42°00'
41°52'30"
41°45'
EXPLANATION
OUTWASH
0 TO 50 FEET THICK
50 TO 100 FEET THICK
100 OR MORE FEET THICK
TILL
INCLUDES MIXED DEPOSITS AND BEDROCK
DASHED CONTACT INDICATES THE EXTENT OF OUTWASH IN AREAS WHERE GEOLOGIC DATA ARE SCANTY
BOUNDARY OF GROUND-WATER STUDY AREA
VILLAGE
SCALE:
1 1/2 0 1 MILE
Geology furnished by W B Allen, W H Bierschenk, and G W Hahn, 1957
Base map prepared from U. S. Geological Survey topographic maps by S. M. Lang, and G W Hahn, 1957

Map showing the distribution and thickness of outwash in ground-water reservoir areas in northeast Rhode Island.

PLATE 4


71°22'30"
41°45'
VIDENCE - WARWICK AREA
RIVER
PAWTUXET
POST ROAD
OCCUPESSATUXET ROAD
WEST SHORE ROAD
WARWICK AVENUE
WARWICK POND
WEST SHORE ROAD

551
R346g
no.11

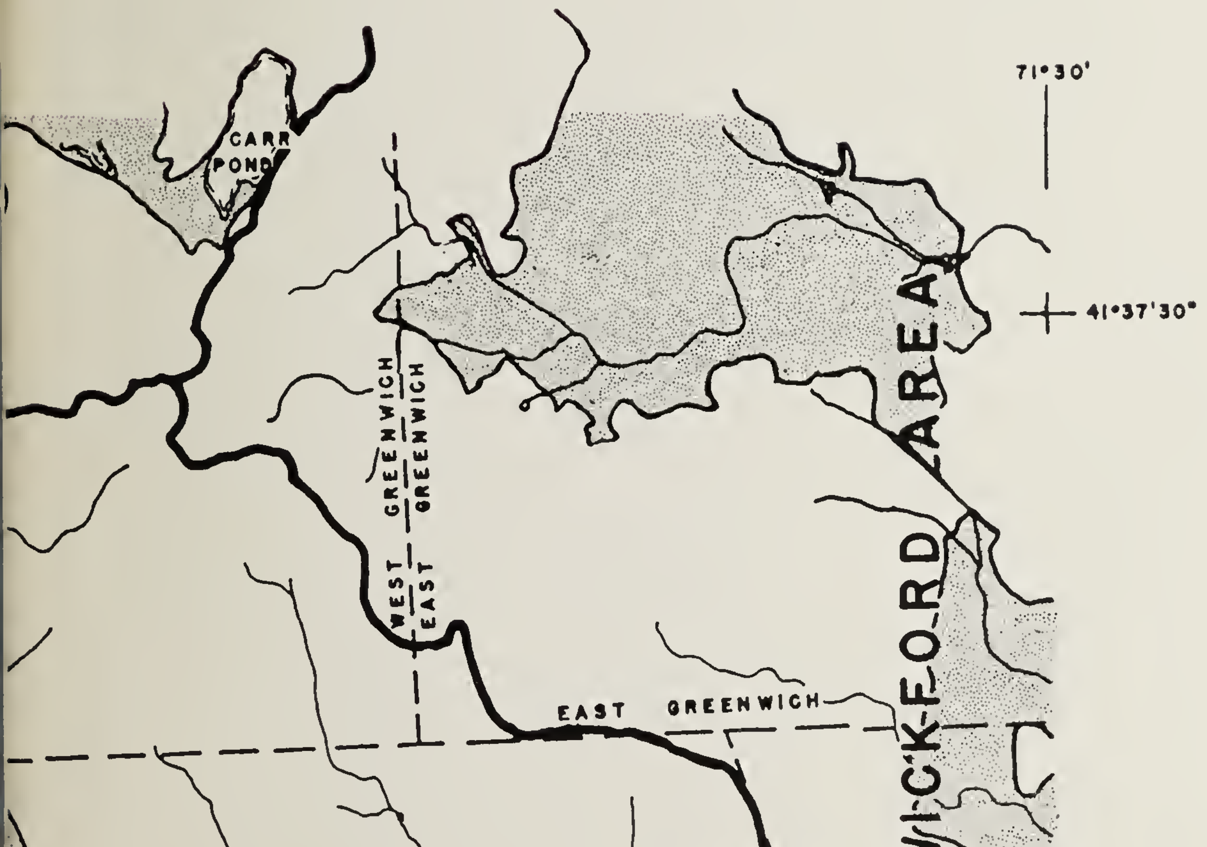


GEOLOGY BY W.B. ALLEN, W.H. BIERSCHENK, AND G.W. HAHN

BASE MAP PREPARED FROM U.S. GEOLOGICAL SURVEY
TOPOGRAPHIC MAPS BY S.M. LANG AND G.W. HAHN, 1957

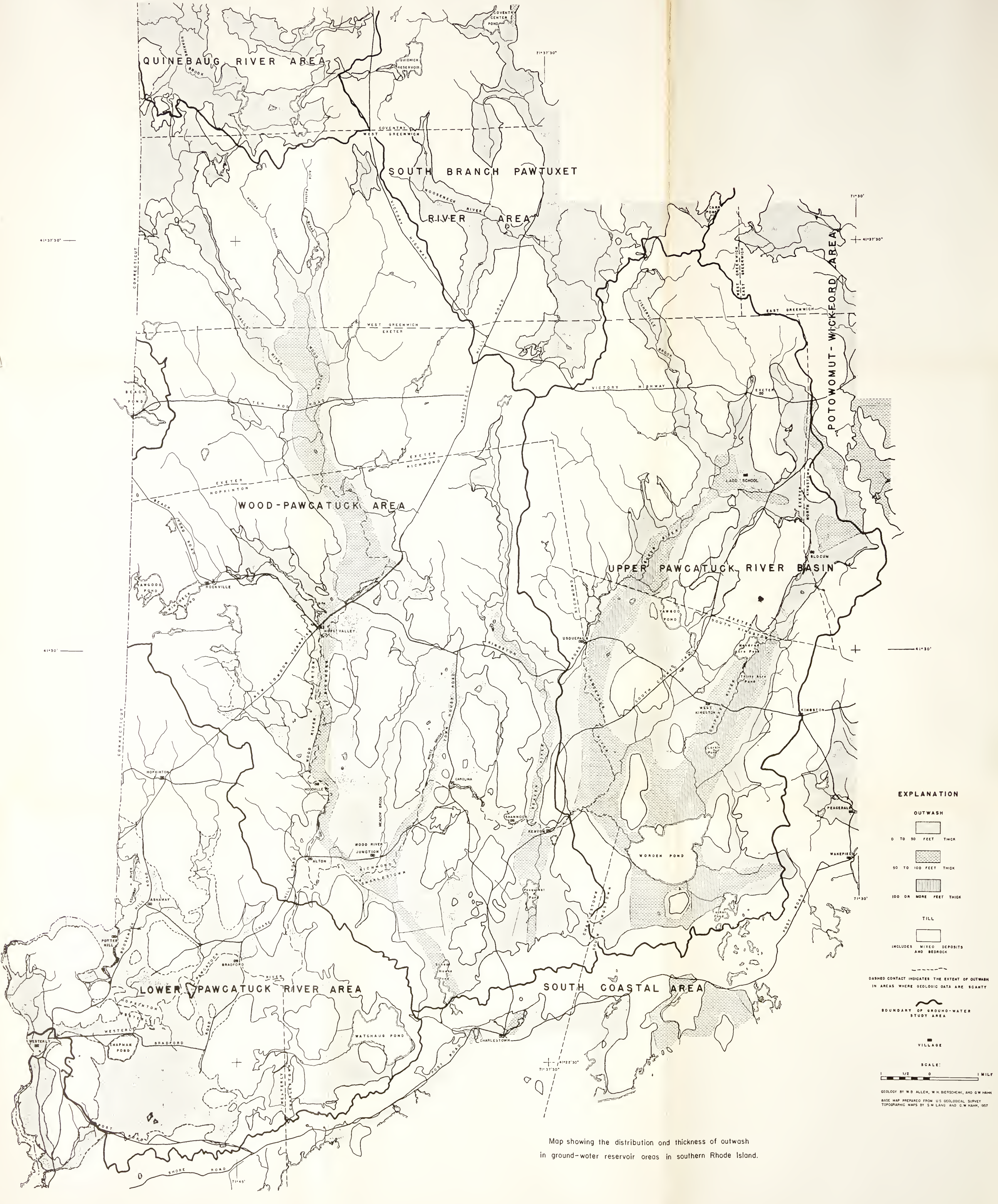
Map showing the distribution and thickness of outwash
in ground-water reservoir areas in central Rhode Island.

PLATE 5



CARR POND
WEST GREENWICH
EAST GREENWICH
EAST GREENWICH
UT- WICKFORD AREA
71°30'
41°37'30"

557
R346g
no.11



GEOLOGY BY W.B. ALLEN, W.H. BIERSCHENK, AND G.W. HAHN

BASE MAP PREPARED FROM U.S. GEOLOGICAL SURVEY TOPOGRAPHIC MAPS BY S.M. LANG AND G.W. HAHN, 1957

Map showing the distribution and thickness of outwash in ground-water reservoir areas in southern Rhode Island.

REPORTS AND MAPS DEALING WITH GROUND-WATER CONDITIONS IN RHODE ISLAND

PUBLISHED BY THE STATE OF RHODE ISLAND AND PROVIDENCE PLANTATIONS IN COOPERATION WITH THE U. S. GEOLOGICAL SURVEY

GEOLOGICAL BULLETINS:

*No. 1 Progress Report on the Ground-Water Resources of Providence, R. I.; C. M. Roberts and M. L. Brashears, Jr., 1945.

*No. 2 Well and Test Hole Records for Providence, R. I.; C. M. Roberts and H. N. Halberg, 1945.

No. 3 Geology and Ground-Water Resources of the Pawtucket Quadrangle, R. I.; A. Quinn and others, 1948.

*No. 4 Geology and Ground-Water Resources of the Georgiaville Quadrangle, R. I.; G. M. Richmond and W. B. Allen, 1951.

*No. 5 Geology and Ground-Water Resources of Woonsocket, R. I.; A. W. Quinn and W. B. Allen, 1950.

*No. 6 Ground-Water Resources of Rhode Island; W. B. Allen, 1953.

No. 7 Ground-Water Resources of the Bristol Quadrangle, R. I.-Mass.; W. H. Bierschenk, 1954.

No. 8 Ground-Water Resources of the East Greenwich Quadrangle, R. I.; W. B. Allen, 1956.

No. 9 Ground-Water Resources of the Kingston Quadrangle, R. I.; W. H. Bierschenk, 1956.

No. 10 Ground-Water Resources of the Providence Quadrangle, R. I.; W. H. Bierschenk, 1959.

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No. 1 Ground-Water Levels in Rhode Island, 1956; W. B. Allen and S. M. Lang, 1957.

No. 2 Ground-Water Levels in Rhode Island, 1957; G. W. Hahn and J. A. Wosinski, 1960.

No. 3 Hydraulic Characteristics of Glacial Outwash in Rhode Island; S. M. Lang, W. H. Bierschenk, and W. B. Allen, 1960.

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*No. 1 Ground-Water Conditions in the Vicinity of Mashapaug Pond, Providence, R. I.; R. M. Jeffords and W. B. Allen, 1947.

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*No. 3 Ground-Water Resources of Bristol, Warren, and Barrington, Bristol County, R. I.; W. B. Allen and J. A. Blackall, 1950.

*No. 4 Geologic Factors Affecting the Yield of Rock Wells in Southern New England; R. V. Cushman, W. B. Allen, and H. L. Pree, 1953.

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GROUND-WATER MAPS:

GWM 1 Ground-Water Map of the Wickford Quadrangle,
and L. Y. Marks, 1959.

GWM 2 Ground-Water Map of the Slocum Quadrangle, R. I.; G. W. Hahn, 1959.

GWM 3 Ground-Water Map of the Crompton Quadrangle, R. I.; W. B. Allen, K. E. Johnson, and R. A. Mason, 1959.

GWM 4 Ground-Water Map of the East Providence Quadrangle, Mass.-R. I.; W. B. Allen and L. A. Gorman, 1959.

GWM 5 Ground-Water Map of the Narragansett Pier Quadrangle, R. I.; G. W. Hahn, 1959.

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GWM 7 Ground-Water Map of the Fall River Quadrangle, Mass.-R. I.; W. B. Allen and D. J. Ryan, 1960.

GWM 8 Ground-Water Map of the Coventry Center Quadrangle, R. I.; R. A. Mason and G. W. Hahn, 1960.

GWM 9 Ground-Water Map of the Carolina Quadrangle, R. I.; A. M. LaSala, Jr., and G. W. Hahn, 1960.

GWM 10 Ground-Water Map of the Oneco Quadrangle, Conn.-R. I.; K. E. Johnson, R. A. Mason, and F. A. DeLuca, 1960.

GWM 11 Ground-Water Map of the Quonochontaug Quadrangle, R. I.; A. M. LaSala, Jr., and K. E. Johnson, 1960.

GWM 12 Ground-Water Map of the North Scituate Quadrangle, R. I.; S. J. Pollock, 1960.

GWM 13 Ground-Water Map of the Voluntown Quadrangle, Conn.-R. I.; A. D. Randall, W. H. Bierschenk, and G. W. Hahn, 1960.

An asterisk (*) indicates that the report is out of print, but such reports are available for consultation in certain libraries.

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